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PREVENTING LANDFILL LEACHATE CONTAMINATION OF WATER

GULF SOUTH RESEARCH INSTITUTE

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

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PREVENTING LANDFILL LEACHATE CONTAMINATION OF WATER

By

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Available commercial materials and industrial waste products that could possibly be used as sanitary landfill sealants were tested in elemental test columns (with the use of synthesized garbage) that simulated field conditions. These materials were then applied to small field test pits filled with municipal garbage. The test pits were equipped with sampling wells, within and around each pit, to monitor any leachate which escaped from the cells. The analytical parameters (BOD, COD, and others) were compared with baseline data obtained from local area wells to determine the degree of effectiveness of the test materials.

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

In an attempt to solve the problem of solid waste disposal, a study was done to identify and test materials that would be useful in sanitary landfill engineering to prevent or limit permeation of contaminating leachates through the landfill soil into adjacent streams or ground water tables.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center, Cincinnati

ABSTRACT

A survey was made during the study period of available commercial materials and industrial waste products which could possibly be used as sanitary landfill sealants. These materials were tested in elemental test columns, using synthesized garbage-simulating field conditions. These materials were then applied to small field test pits filled with municipal garbage. The test pits were equipped with sampling wells, within and around each pit, to monitor any leachate which escaped from the cells. The analytical parameters (BOD, COD, and others) were compared with baseline data obtained from local area wells to determine the degree of effectiveness of the test materials.

The conclusions of this study are based on results obtained to date and do not constitute a firm basis for predicting the performance of the materials tested herein under actual sanitary landfill conditions.

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Foster Grant Company, Inc.
Pennwalt Chemical Corporation
Esso Standard Oil Company
Dow Chemical Company
Enjay Chemical Company
Allied Chemical Corporation
Kaiser Aluminum and Chemical Corporation
Monochem, Inc.
Wyandotte Chemicals Corporation
Carlisle Tire and Rubber Division
Cities Service Oil Corporation
Rubicon Chemicals

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INTRODUCTION

Solid waste disposal has been studied extensively along the Pacific Coast, in the North-Central states, and in the Northeast. It is known from these studies that the relative merits of the various methods of disposal are affected by environmental characteristics, such as temperature, rainfall, earth structure, and cultural patterns. A review of solid waste research literature, [1] [2], indicates that only a small amount of work has been conducted in the Gulf Coast region. With the exception of the work by Schneider in New Orleans [3] [4], knowledge of behavior of sanitary landfills in the wet, porous, hot, and near-sea-level coastal region is minimal. The problem of ground water contamination from sanitary landfills is of particular importance. Heavy rainfall and warm climatic conditions greatly speed up the process of decomposition in this area, in comparison with other areas of the country [3] [4].

The principal process [5] involved in the introduction of undesirable substances to ground water through refuse disposal sites are considered to be (a) infiltration, (b) percolation, (c) refuse decomposition, (d) gas production and movement, and (e) leaching and ground water travel. The appearance of percolation in high precipitation areas may be delayed for years because of the high moisture-retaining capacity of combustible rubbish, and because heat liberated in decomposition of refuse may accelerate evaporation.

Refuse contains mineral and organic substances in quantities capable of seriously damaging underground water supplies. The organic matter will undergo aerobic and anaerobic decomposition and produce large volumes of carbon dioxide, thus seriously degrading ground water by dissolving calcium, magnesium, and iron. Leaching and ground water travel contribute chloride, total hardness, total solids, total organic nitrogen, and nitrate and biological contamination as well, in some instances.

These characteristic contributions of landfills to ground waters, based on finding by Andersen [6] and Calvert [7], vary, depending upon the geographic location of the landfill areas. Andersen concluded that excessive hydrogen-ion concentration is detrimental to water quality, but that pH is a poor indicator of pollution because of the large change of hydrogen-ion concentration needed to show a change in pH. The presence of carbon dioxide and its yield of carbonic acid lowers the pH. Under anaerobic conditions, nitrates are reduced to nitrites in the landfill, which may be further reduced to either ammonia by a few species of bacteria or nitrogen gas, which escapes to the atmosphere.

In Andersen's study, there was complete utilization of nitrates due to the anaerobic process. He found that chlorides were the most sensitive parameter and considered the chloride ion the most suitable indicator of leaching from a landfill, since it is easily measured, not readily absorbed by soil formations, and not altered by biological processes.

Sanitary landfills will undoubtedly be the only practical method, in the foreseeable future, of solid waste disposal in smaller municipalities and communities. The high cost of incineration rules out this method in these small cities. Fortunately in most cases, the availability of land for this purpose is less of a problem in rural areas. In view of the ground water contamination problems cited previously, it should be of practical value to provide methods for shielding or preventing leachate penetration into the subsurface ground by any means available. It seems logical that the use of sealants (be they commercial products or effective sealant waste materials) to render the land available for a sanitary landfill harmless to the environment would be a major contribution to the technology of waste disposal methods.

SCOPE AND OBJECTIVES

This project was undertaken by Gulf South Research Institute to identify and test materials which might prove useful in sanitary landfill engineering to prevent and/or limit permeation of contaminating leachates through the landfill soil into adjacent streams or ground water tables. Test were made to identify pollutants or to otherwise characterize the leachate escaping from the test cells.

A broad assumption was made that the municipal refuse used to charge the test cells would contain, in general, the character of leachate described by A. A. Fungaroli, Ph.D., and others [6]. It was believed that no single test material could be expected to perform as a universal barrier; i.e., prevent any conceivable pollutant from permeating through the soil, regardless of the concentration. On the basis of this belief, it was thought that the need to analyze the municipal refuse used to charge the cells would be limited to academic value related only to the particular charge used in the test. There would be no guarantee that the refuse charge of one cell would be the same, physically and chemically, as the next.

Since this information would not qualify the performance of the material against other unknown possible pollutants in municipal refuse, it was decided an analysis of the refuse was not justified within the scope of the research effort and the budget constraints. An accurate analysis of the refuse and the possible contaminants it might produce (under the many possible mixes and decomposition conditions) would be a monumental task, if possible at all.

Furthermore, the waste materials used as sealants in the tests were not quality-controlled, because of their generation in the

manufacturing process control stream. For this reason, an accurate physical and chemical composition of each could not be predicted from batch to batch. In addition, the types of soils and climatic conditions in which the test materials might subsequently be used might enter into the performance role of each material.

No effort was made to trace the migration distance and paths of the leachates (or generated gases) permeating the barrier walls beyond the immediate vicinity of the test wells. The ultimate path of the ground water movement is not important to this study. Only the hydraulic dynamics in contact with the cell linings (barrier materials) are of interest in analyzing the performance of the test materials.

The results of this project, therefore, are expressed in terms of the graphic information plotted for each cell and the narrative interpretations presented for each at the conclusion of this report.

These observations are offered as an apology and/or rationale for the lack of more scientific evidence to support the findings of this study.

ANALYSIS OF SEALANT MATERIALS

Types of Material Available

Bottom sealants for waste disposal pits can be classified as two general types: (a) membrane and (b) barriers, the low permeability and thickness of which restrict the flow of leachates. Both sealant types must be applied with care so that no breaks or voids exist which will allow direct seepage to underlying water-bearing formations or aquifers.

Membrane sealants include asphalt-impregnated felt, rubber sheets, and polyethylene or polyvinyl chloride sheets. Membrane sealants have the disadvantage of possible puncture by the solid waste during placement and compaction. The disadvantage, however, can be overcome by placing a buffer zone of the excavated overburden between the soil and waste. Cost of the plastic and asphaltic sheets is approximately one cent per square foot. Installation, which must be by hand, increases the cost to from five cents per square foot (*Chemical Week*, November 1967) to 23 cents per square foot (*Civil Engineering*, May 1970). Installation costs are governed by the installation technique and local labor cost.

Sealants that depend upon low permeability and thickness include clays, soil-chemical mixtures, soil-asphalt mixtures, and soil-clay mineral mixtures. These sealants have the advantage of being installed by mechanical equipment and, therefore, have a lower cost of installation. Soil mixtures seal the bottom because they have a broad range of particle sizes which fit together when mixed so that practically all the voids are filled. This process is aided, in the case of soil-chemical and soil-asphalt mixtures, by a coating of the soil particles with the material added. The degree to which soil mixtures are able to seal depends not only on a broad range of particle sizes, but in the clay size of less than two microns, upon particle structure and shape. The clay minerals halloysite, sepiolite, and attapulgite have a tubular shape and, therefore, are more permeable than the other clay minerals.

Structural formation of clay minerals accounts for differences in their plasticity and ability to absorb moisture. Layers of montmorillonite are more easily separated than kaolinite, because adjacent layers of montmorillonite face each other with negatively charged oxygens, whereas, in kaolinite, an oxygen faces a hydroxyl. The positive hydrogen ion in kaolinite reduced the repulsive forces of the oxygens and is, thereby, more tightly held than in montmorillonite.

Blankets of soil mixtures have an estimated cost of $250 to $400 per acre (*Chemical Week*, November 1967). The thicknesses on which these blankets were estimated may not be sufficient to contain the fluids produced by solid wastes. This opinion is based on experience that showed the clay mineral montmorillonite increases in volume by approximately 75 percent, resulting in a large permeability increase, when subjected to a strong sulphuric or phosphoric acid environment. In other words, the clay material structure could be destroyed, making it valueless as a sealant, if exposed to similar landfill conditions.

Because of the relatively high cost of installation of membrane-type sealants and the need for thickness in soil mixtures, the best solution seems to be the selection of a disposal site that has a natural clay layer *of sufficient thickness* to contain the waste-produced leachates. The efforts of this research work precludes the availability of natural clays at the disposal site; therefore, this report centers on a survey of other products and methods of sealing a landfill.

Types of Materials Surveyed

Before various types of sanitary landfill soil sealants were field-tested, a survey was conducted of available commercial soil sealants and industrial waste products which could be useful in this study. The selection of a potential material for the sealing of

sanitary landfills was based upon several parameters, most important of which were

1. Stability to the chemical and mechanical conditions experienced in a landfill
2. Cost and availability of the potential material
3. Application, handling, and storage performance
4. Ability of the material effectively to restrict the movement of refuse leachate

The following list indicates the 28 industrial waste and commercial products identified as possible soil sealants for use in sanitary landfill operations:

1. Uniroyal rubber polymer, waste product, "floor"
2. Uniroyal tar chunks, brittle
3. Uniroyal Royalene Process sump waste
4. Uniroyal rubber polymer, waste "floc"
5. Uniroyal effluent sludge
*6. Ethyl alcohol waste, solid, C^{20+}
7. Foster Grant styrene tars
8. Foster Grant polyethylbenzene, 6¢/gal
9. Foster Grant polystyrene, "Lome 4" inexpensive product
*10. Armour cationic asphalt emulsion (pond seal)
11. Esso asphalt
12. Dow Saran resin, off-grade, F-329
*13. Dow Latex 464, commercial product, 50% solids
*14. Dow experimental styrene latex, cx #4624, 50% solids
*15. Enjay CTLA polymer
*16. Enjay aromatic tar s-2,
17. Allied Chemical polyethylene, granular, (dry)
18. Kaiser red mud, washed, dried
*19. Kaiser red mud slurry, caustic

20. Monochem coke from acetylene unit
21. Monochem waste polymer
22. Monochem carbon soot slurry
23. Wyandotte T.D.A. tar
24. Carlisle Tire & Rubber Division, "sure-seal" rubber membrane
25. Cities Service Oil Co., scrap butyl rubber
*26. LCA resin-amorphous polypropylene (Hercules)
27. Rubicon Chemicals toluene diisocyanate
28. Baroid bentonite (mud grade)

Only those materials marked in the list with an asterisk passed the preliminary screening.

These materials were suggested or recommended by the respective plant managers on the bases of inertness, biodegradability, permeability, cost, and other considerations peculiar to this application. The commercial products listed were not necessarily intended for use as soil sealants, but were suggested for this purpose because off-grade or off-specification samples of these products become available as "waste" products which might be used for barrier materials at the refuse/soil interface in sanitary landfills. The research team did, however, investigate commercial soil sealants, as well as continue the search for additional industrial waste and other materials suitable for this purpose.

DESCRIPTION OF TEST SITE AND AREA GEOLOGY

The test site for the study of the landfill leachate contamination of water was located on GSRI property, riverward from the office and laboratory buildings, with a land surface elevation of approximately 20 feet mean sea level (msl). The area is underlain by sediments of Recent age, which are usually termed "river alluvium." The uppermost layers are silt, silty clay, and clayey silt, all of which contain streaks of sand. From the land surface down to a depth of from 40 feet to 50 feet, these alternating, intercalating layers of fine-grained material continue. Below the silts and clays is a sand--silty in its upper section and increasingly clean at depth. Underlying the sand, at a depth of possibly 90 feet below the land surface, is a very permeable aquifer, in hydraulic contact with the Mississippi River.

The hydraulic contact between the Mississippi River and the underlying sands and gravels of the river alluvium means that the river stages will affect water levels throughout the area. Meyer and Turcan (1955, p. 20) have shown the effect of river stage on the water levels of EB-242, a well approximately 180 feet deep, located in the river alluvium some two miles from the river on the Ben Hur Farm of Louisiana State University, which is less than three miles from the test site.

Water levels in the area change in response to two natural causes: (a) the percolation of rain into the ground, and (b) the change in river stage. Groundwater flow in the area is subject, potentially, to change in direction, depending upon the relative efficacy of these two causes. During low water, rainfall percolation should be most significant, and the direction of flow should be generally riverward. During extended periods of high water in the river, the direction of flow will be reversed: water levels will be high near the river and the flow will be landward.

For purposes of the field test, conditions at the test site are representative of those found in the alluvium of the Mississippi River from Donaldsonville, Louisiana, to as far north as Minnesota; of portions of the lower Ohio River, the Arkansas River, and the lower Missouri River; not to mention such tributaries as the Wabash, the Miami, and the Illinois rivers. Principal differences in surficial geology, as compared with the test site, are the existence of sand closer to the land surface, or alternately, a layer of tight clay closer to the land surface. The GSRI site is generally representative of the alluvial valleys: if the pit linings do not permit leachate to enter the aquifer here, such linings can be used with confidence elsewhere.

Test Site Borings

A 12-foot continuous soil boring, showing three distinct soil layers, was made at the pit sites. The first layer consisted of 22 percent clay, 70 percent silt, and 8 percent sand-sized particles, extending from the surface to a depth of three feet. The second layer, extending from three to 5.5 feet, contained 15 percent clay, 75 percent silt and 10 percent sand-sized particles. Permeability of a disturbed sample in this strata was measured in the laboratory by the falling head method and was found to be 2.5×10^{-5} cm/sec. This permeability is considered to be unsuitable for a water-bearing formation, but much higher than a clay layer, which is usually considered impermeable. The bottom layer extended from 5.5 feet to 12 feet, the point at which the hole was terminated. The bottom layer contained 65 percent clay, 34 percent silt, and one percent sand-sized particles. This material was highly plastic and, due to the large percent of clay particles, was relatively impermeable.

Exhibit A shows core samples from test boring, and Exhibit B is a photograph of drilling used for soil core samples. Figures 1, 2, and 3 are semi-log plots showing the graduation at the various depths of the borings. Exhibit C is the actual soil classification, as reported by ETCO Engineer & Associates.

Exhibit A

SAMPLES FROM TEST BORING

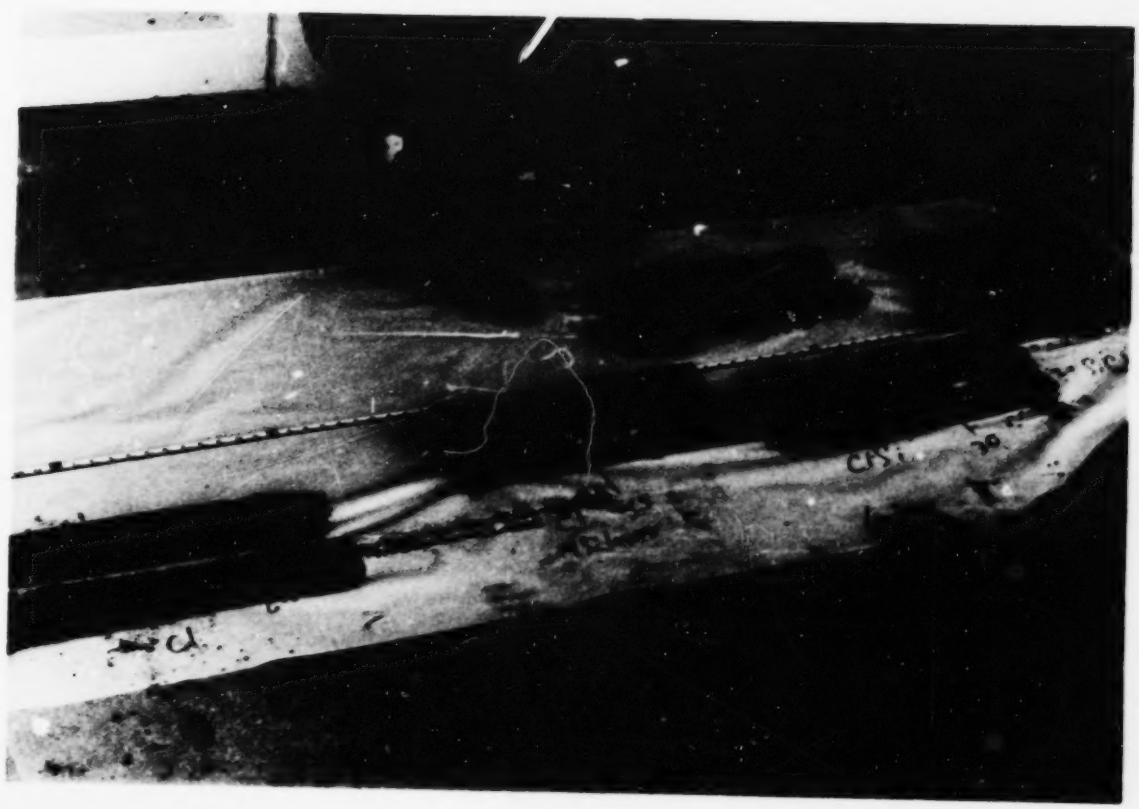
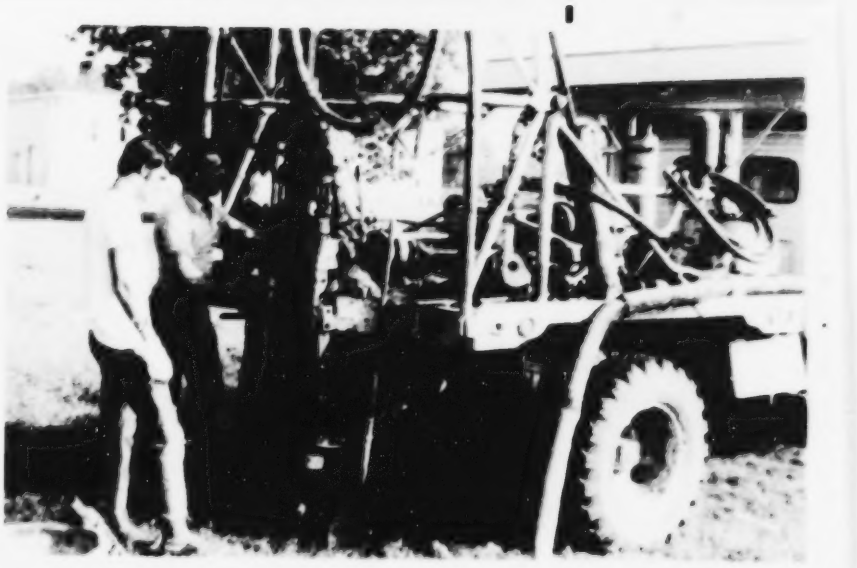


Exhibit B

DRILLING USED FOR SOIL CORE SAMPLES



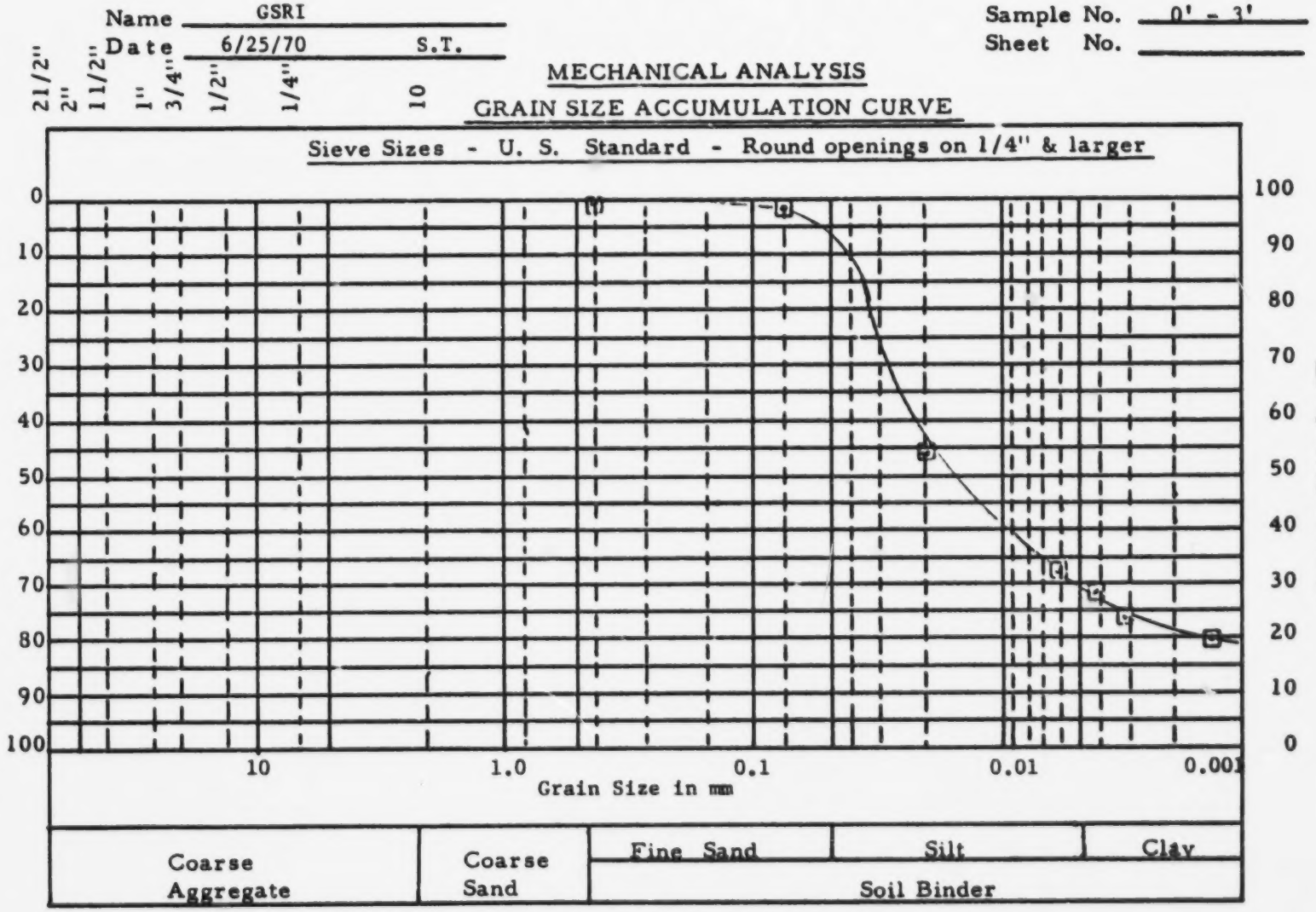

Name GSRI
Date 6/25/70 S.T.
Sample No. 0' - 3'
Sheet No.
MECHANICAL ANALYSIS
GRAIN SIZE ACCUMULATION CURVE
Sieve Sizes - U. S. Standard - Round openings on 1/4" & larger
21/2" 2" 11/2" 1" 3/4" 1/2" 1/4" 10
0 10 20 30 40 50 60 70 80 90 100
100 90 80 70 60 50 40 30 20 10 0
Percent Finer by Wt.
10 1.0 0.1 0.01 0.001
Grain Size in mm
Coarse Aggregate
Coarse Sand
Fine Sand
Silt
Clay
Soil Binder

Fig. 1 GRAIN SIZE ACCUMULATION CURVE (Sample 0' - 3')

Name GSRI

Date 6/25/70 S.T.

Sample No. 3' - 5-1/2'

Sheet No.

MECHANICAL ANALYSIS

GRAIN SIZE ACCUMULATION CURVE

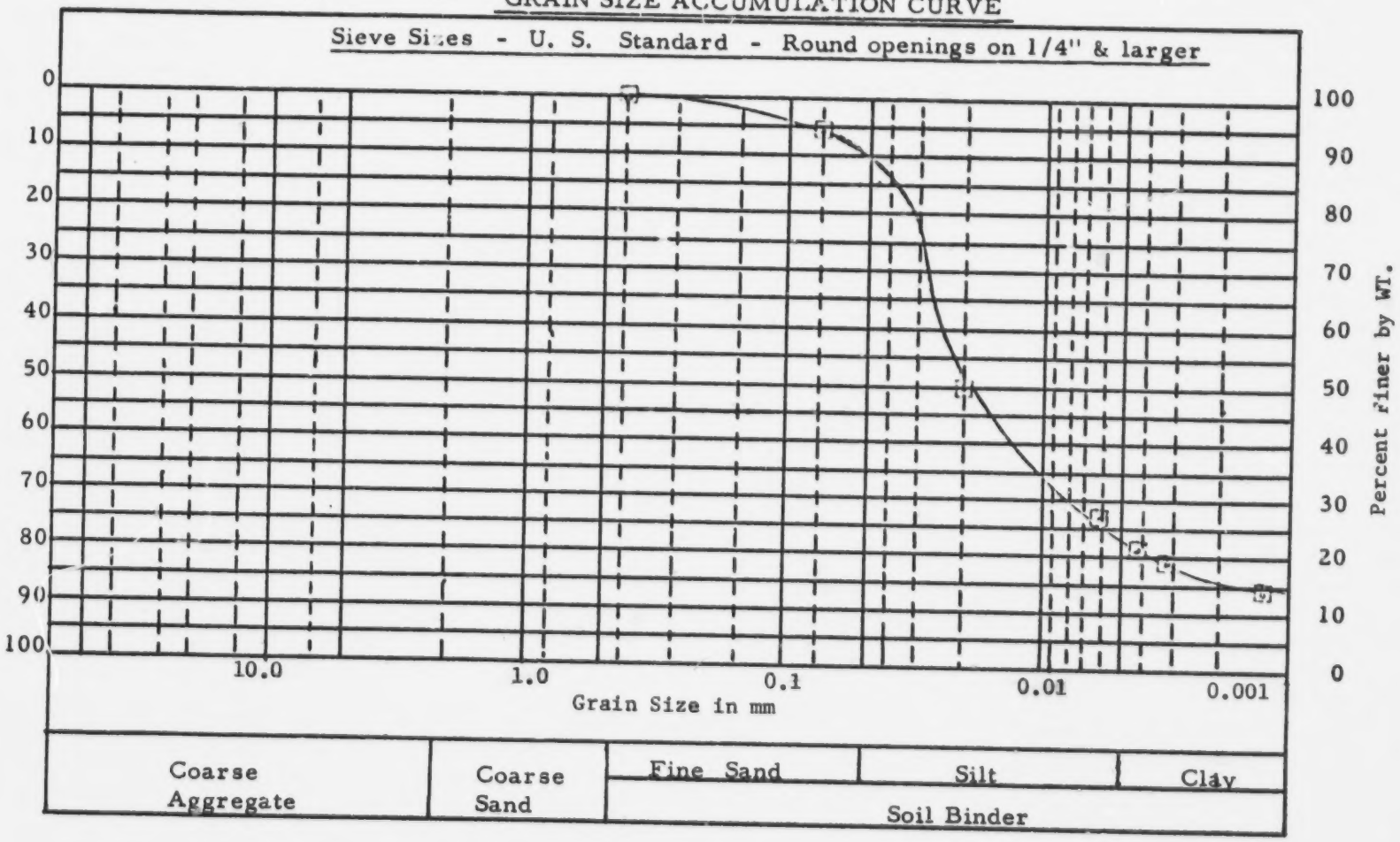


Fig. 2 GRAIN SIZE ACCUMULATION CURVE (Sample 3' - 5-1/2')

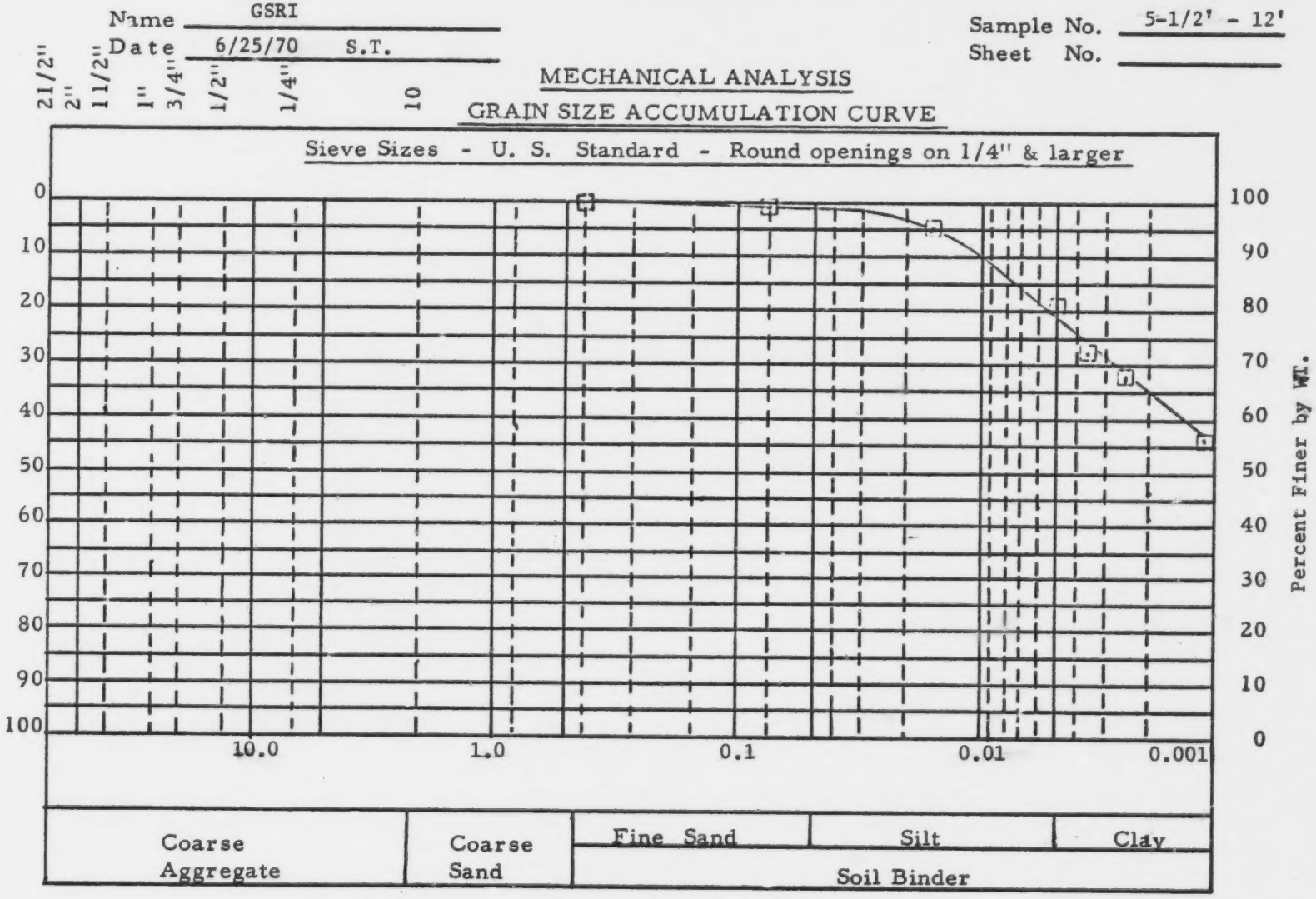

Name GSRI
Date 6/25/70 S.T.
Sample No. 5-1/2' - 12'
Sheet No.
MECHANICAL ANALYSIS
GRAIN SIZE ACCUMULATION CURVE
Sieve Sizes - U. S. Standard - Round openings on 1/4" & larger
21/2" 2" 11/2" 1" 3/4" 1/2" 1/4" 10
0 10 20 30 40 50 60 70 80 90 100
100 90 80 70 60 50 40 30 20 10 0
Percent Finer by WT.
10.0 1.0 0.1 0.01 0.001
Coarse Aggregate
Coarse Sand
Fine Sand
Silt
Clay
Soil Binder

Fig. 3 GRAIN SIZE ACCUMULATION CURVE (Sample 5-1/2' - 12')

Exhibit C

LABORATORY LOG OF BORING FOR G.S.R.I.

70-264
June, 1970

DATE 6/18/70 TYPE: 3" Shelby Tube LOC: Indicated in field by Mr. S. I. Thornton

DEPTH, FEET	SYMBOL	CORES	DESCRIPTION	BLOWS PER FOOT	LIQUID LIMIT	PLASTIC LIMIT	UNIT DRY WT LB/FT³	COHESION, TONS/FT² * 0 0.5 1.0 1.5 2.0 2.5 / MOISTURE CONTENT, % 0 10 20 30 40 50	ELEVATION FEET
			Very stiff brown silty clay w/silt streaks						
5			Very loose brown clayey silt						
10			Soft-medium gray clay w/silt streaks & layers to 6.5' w/organic matter below 8'						
			Bottom @ 12'						
15									

Note: Above are field classifications only.

Etco Engineers and Associates

*Approximate: from Pocket Penetrometer Readings

Initial Test Site Conditions

The site plan illustrated in Fig. 4 indicates each of the experimental sanitary landfill pits which were charged August 27, 1970. The points A, B, C, D, and E indicate the location of groundwater sampling and monitoring wells, which are 12 feet deep. The water table in this area fluctuates between six and nine feet below 20 feet msl. There seemed to be no correlation between the stages (levels) of the Mississippi River (one mile away) and the test site water table, as previously stated. The fluctuations were directly related to rainfall and indicate a 12- to 18-hour lag in effect (Table I).

An effort was made to relate rainfall amount and intervals with variations in chemical data. Since all of the chemical parameters were low for the baseline wells, all interpretations were not conclusive. As stated previously, there is a lag in response time (rise of water table) after a rainfall. A rainfall of 0.10" merely serves to maintain the previous water level reading. One-half inch to one inch is required to raise the water table a significant amount.

The chlorides were surprisingly low, but were a good parameter of pollution, since two recent leachate samples contained 10 times the background levels. The effect of rainfall on chlorides could not be evaluated for the baseline wells. There seemed to be a slight increase of biological oxygen demand (BOD) with rainfall. No pattern could be established for sulfate. Nitrates were too low to establish a relationship. Total solids increased following significant rainfalls.

Comparison of water quality among the five baseline wells was limited, as in the case of the rainfall relationships described in the preceding paragraph, because of the low values found. Again, however, this serves to magnify and permit rapid detection of contaminants. All wells yielded high dissolved solids, as compared with the local water supplies. Well B had the only significant difference in pH, compared with the other four. The total solids for this well were also lower than those of the other wells. The sulfate level for this well was also markedly lower.

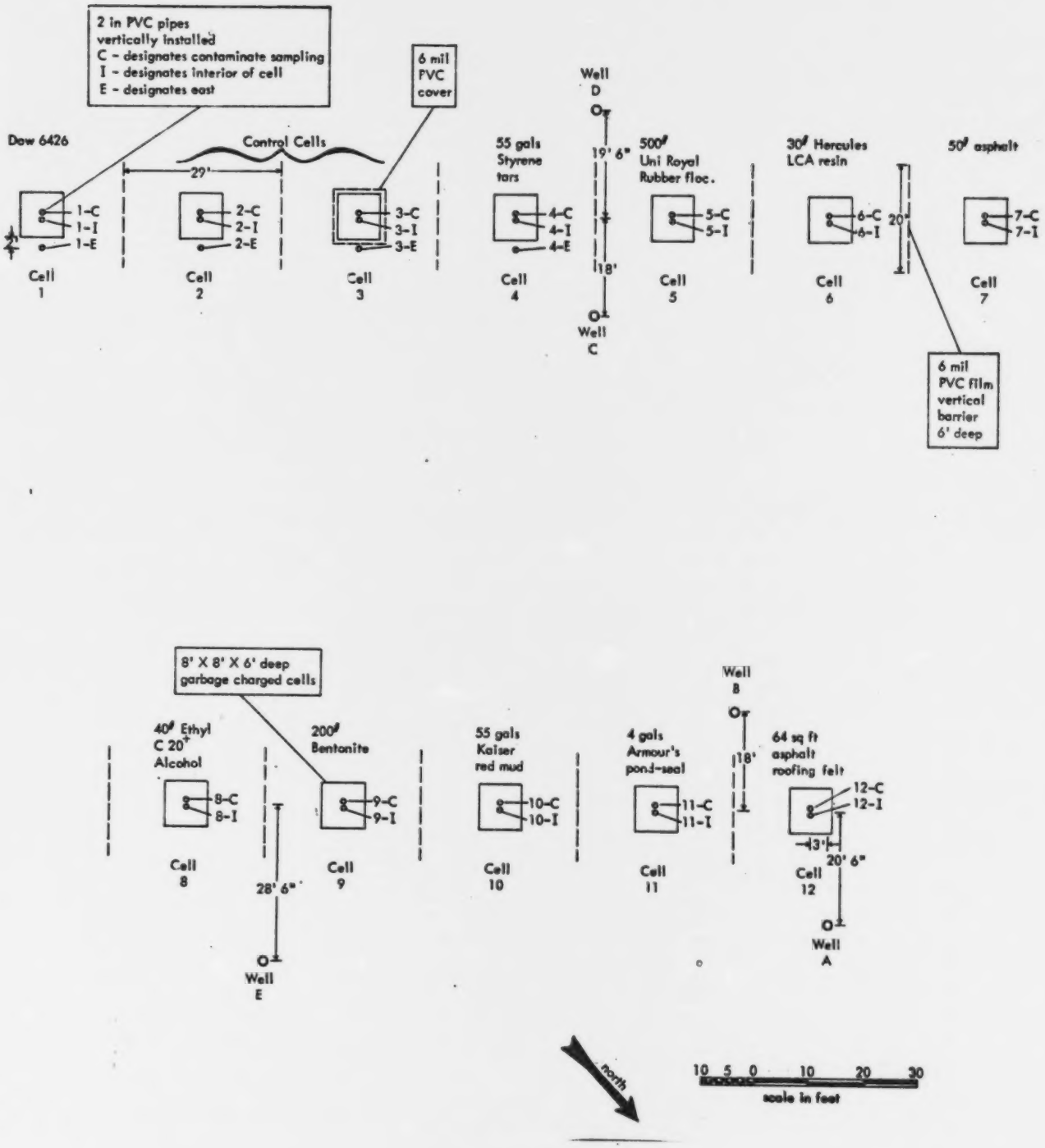


Fig. 4 SANITARY LANDFILL TEST PLOT

Table I

BASELINE MONITORING WELLS
WATERTABLE DEVIATIONS

Days Observed	River Stage (Feet)	Baseline Wells				Monthly Rainfall (Inches)
		A	B	C	D	
May 1970						
5-4	29.0	7'9"		9'2 1/2"		2.44
5-6	29.4	7'7 1/2"		9'5 1/2"		0.00
5-7	29.8	7'11"		9'3 1/2"		0.00
5-8	30.2	7'10 1/4"		9'3 3/4"		0.00
5-12	31.2	8' 1/4"		9'5 1/4"		0.00
5-13	31.4	8' 1/4"		9'5 1/2"		0.01[a]
5-17	32.6	8'1"		9'5"		0.30
5-19	32.7	8'2"	8'9 1/4"	8'6"	8'7"	0.00
5-20	32.9	8'1 1/4"		8'6 3/4"		0.03
5-21		8'1 1/2"		8'7 1/2"		0.00
5-25	31.3	8'1"	8'9 1/2"	8'8"	8'7 1/2"	0.10[b]
5-27	31.3	8'3 1/2"	8'10"	8'8"	8'7"	0.27
5-28	31.3	8'3 1/2"	8'9"	8'8"	8'8 1/2"	
5-29	30.2	8'5"	9'1/2"	8'9 1/4"	8'8 3/4"	0.50
Maximum	32.9	8'5"		9'5 1/2"		3.65
Minimum	29.0	7'7 1/2"		8'6"		
Deviation	3.9	0'10 1/2"		0'11 1/2"		
September 1970						
9-1	7.8	8'9"	8'2 3/4"	9'2 1/2"	8'5 1/4"	1.60
9-2	7.8	8'2 1/2"	8'3 1/4"	8'10 1/4"	8'5 1/4"	0.02
9-3	7.8	8'5"	8'63/4"	8'2 1/2"	8'5 1/4"	0.52
9-4	7.7	8'1 1/2"	8'9"	8'4"	8'1 3/4"	0.00
9-5	7.5	8'4 1/2"	8'4 1/4"	8'10 1/2"	8'3 1/2"	0.00
9-9	6.5	7'11 1/4"	8'0"	8'6 1/2"	7'8 1/4"	1.60[c]
9-10	6.0	7'10 1/2"	7'11"	8'5 1/2"	7'11 3/4"	0.32
9-11	6.0	7'8 1/2"	8'3 1/4"	8'6"	7'11 3/4"	0.00
9-15	6.4	8'0"	8'2"	8'7"	8'2 1/4"	0.19
9-16	7.0	7'8 3/4"	7'5"	8'2 1/2"	7'9 1/2"	1.16
9-17	6.8	7'8 1/2"	7'2"	8'1 1/4"	7'6 1/2"	0.00
9-28	9.3	7'6 1/4"	7'8"	8'4 1/2"	8'0"	3.91[d]
9-29	9.8	7'5 1/4"	7'7"	8'3 1/4"	7'10 1/2"	0.00
9-30	10.5	7'6"	7'7 1/4"	8'3 3/4"	7'11"	0.00
Maximum	9.8	8'9"	8'9"	9'2 1/2"	8'5 1/4"	9.32
Minimum	6.0	7'5 1/4"	7'2"	8'2 1/2"	7'6 1/2"	
Deviation	3.8	1'3 3/4"	1'7"	1'0"	0'10 3/4"	

[a] 5-11 [b] 5-24 [c] 9-8 [d] 9-19 & 9-27

There was no appreciable difference in the total solids among wells A, C, D, and E. Differences in BOD were marginal, although Well C could be considered somewhat lower. The chloride values were too low to compare realistically. Sulfate values among wells placed Well B as the lowest value, and Well D as the highest value. Nitrates and phosphates were too low to interpret for comparative purposes. Additional parameters, such as chemical oxygen demand (COD) and nitrate, provided additional bases for characterizing these baseline wells.

Test Pit Description

The 8' x 8' test pits (a photograph of which is included in Exhibit D) were excavated to a depth of six feet. An 8' x 8' wood frame, constructed with 2" x 4" timbers, was placed around the grade periphery of the excavation to permit the attachment of a six-mil PVC film material to line the vertical walls of the pit. This material was attached to minimize any throughput of leachate laterally from the cells. The bottom of the pit was leveled and the test barrier material applied so as to overlap the bottom folds of the vertically suspended PVC wall lining. Any throughput, therefore, would necessarily be directed through the bottom layer (test barrier material), comprising approximately 64 square feet of surface area.

The possible leachate escape area was reduced, therefore, from a total contact surface area of approximately 160 square feet (including the vertical wall surface exposed to refuse) to the 64 square feet comprising the bottom or horizontal area. Care was taken in charging the pits with municipal garbage to minimize the tearing or piercing of the vertical PVC wall lining. It would be difficult to prove, however, that some damage did not occur.

Exhibit D-1

TYPICAL FIELD CELL CONSTRUCTION

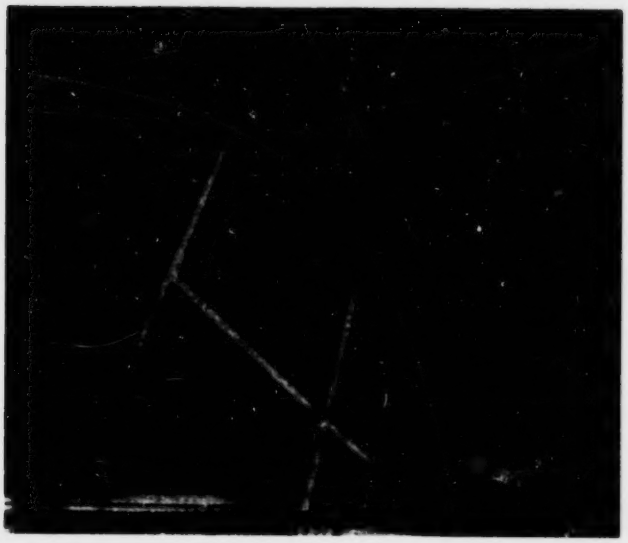


Exhibit D-2

PVC LINER USED TO MINIMIZE LEACHATE THROUGHPUT

Before being charged, the cells were equipped with two 2-inch PVC pipes centered vertically in each cell. The lower end of one pipe was installed in a small sand-filled trap about the size of an eight-quart pail dug in the pit bottom. A skirt of six-mil PVC film, 18 inches in diameter, was slipped concentrically over this vertical pipe and taped at the soil level (bottom of pit) to prevent leachate from channeling through to the sampling trap below.

A second two-inch PVC pipe was installed adjacent to the first pipe for sampling liquids collecting within the cells. This pipe was shorter than the first and was positioned so that the lower end was approximately 18 inches above the barrier material covering the pit bottom surface. Both pipes extended upward about six inches above the soil cover (slightly above grade). Each pipe was fitted with a removable cover (a painted metal food can) to prevent rain and foreign substances from entering. The following paragraphs describe the application of test sealants to the cells.

Application of Test Sealants

Cell 1 was treated with the liquid sealant Dow Chemical CX 4624. Five gallons of this solution was poured over the leveled bottom surface of the test pit. This amounts to approximately .08 gallons per square foot of area.

Cell 2 and 3 were used as control cells, and no sealant was applied.

Cell 4 was treated with 55 gallons of styrene tar. This material was delivered at 190°F., which allowed it to be poured in its liquid form. The application amounts to .85 gallons per square foot.

Cell 5 was prepared with rubber floc waste as a sealant. This material was received from the plant in plastic sacks containing various sizes or chunks of the material. Efforts were made to break, tear, or cut this material into uniform sizes. This was not an easy task, and would therefore be an unfavorable characteristic of the

material for use in the field. Approximately 450 pounds of this material was dumped into the pit and spread around as evenly as possible to give uniform coverage. Since some of the pieces of the material were as large as one cubic foot, compression of the material by the waste load to be added was relied upon to close the gaps in the surface. The material is rubbery and easily compressed. Approximately seven pounds per square foot were applied.

Cell 6 was treated with a melted solution of LCA resin. This material required about two hours of heating outdoors in a metal drum fired by a 50,000 BTU butane gas burner. About .3 gallons per square foot were applied over the cell bottom surface.

Cell 7 was poured with heated asphalt to provide an even coating over the bottom surface of the cell. About 0.15 gallons/per square foot were applied.

Cell 8 was prepared with the Alcohol C^{20+} waste. This material was heated slightly to permit pouring over the surface. About .08 gallons/per square foot was applied.

Cell 9 was prepared with 190 pounds of bentonite. This material was applied in its natural powder form and spread evenly over the surface. Three pounds/per square foot was applied.

Cell 10 was treated with 55 gallons of Kaiser red mud slurry. This material is about 15 percent solids and flows easily. Approximately .85 gallons per square foot were applied to the surface of the cell bottom

Cell 11 was treated with 10 gallons of pond seal. The material flowed easily and spreaded over the soil surface readily. Approximately .15 gallons per square foot were applied.

Cell 12 was floored with three strips of conventional 20-pound asphalt roofing paper. The strips were lapped about six inches and sealed with ordinary roofing lapping compound on all outside edges.

Charging of Cells

Each cell was charged with approximately five cubic yards of municipal garbage delivered from a routine daily collection by compaction trucks of the East Baton Rouge Parish (Louisiana) Refuse Division (shown in Exhibit E). Two truckloads were required for the original 11 test pits. Observation of the garbage during the charging operation revealed that the waste appeared to be "typical" municipal waste; i.e., free of abnormal concentrations of predominate materials which might influence the "normal" leachate composition. As explained earlier in this report, analysis of the refuse was not justified in view of the many other unknown variables related to this effort.

Two of these pits were not provided with a sealant and were reserved as control pits. One was simply charged with garbage and covered with two feet of earth. The second was charged with garbage, covered with about a foot of earth, and then covered with a generously overlapping sheet of six-mil PVC plastic which was covered by an additional one foot of soil cover. The purpose of the PVC-covered control pit was to gauge the performance of a sanitary landfill deprived of the normal surface water seepage occurring during rainfall. This work was completed August 27, 1970.

Rainfall Patterns at the Site

The 1971 annual rainfall pattern at the sanitary landfill test site was particularly adverse in relation to the objectives of the research effort. In addition to the fact that the average precipitation at the site was 20 percent (24.93 inches) below the normal mean (31.61 inches for the first seven months of 1971), the erratic nature of rainfall during this period restricted the accumulations and/or concentrations of collectable leachate for chemical analysis purposes.

Exhibit E

CHARGING OF CELL FROM MUNICIPAL REFUSE TRUCK

For example, the climatology log sheet (Exhibit F) indicates that from January 11 to February 4, 1971 (a period of 24 days), there was only .02 inches of rainfall at the site. After a brief period in which rainfall totaled 2.5 inches, a "dry spell" occurred in which there was less than 3.0 inches of rainfall during a period of 37 days (February 12 through March 18). From March 30 to May 10 (a period of 42 days), there was less than 0.87 inches of rain. From May 13 to July 20 (a period of 69 days), there was less than 4.0 inches of rainfall--at a time when temperatures were beginning to reach summer highs.

In summary, these four periods of sparce rainfall represented a total of 172 days (almost six of the seven months during which leachate samples were collected). During this period, there was less than eight inches of rainfall.

During this prolonged dry period, all surface water that did not run off was immediately absorbed by the near-surface top soil. The water, therefore, did not permeate the top soil to recharge and raise the ground water table which would thereby expose the test pits linings to the possible influx of ground water. These conditions precluded the evaluation of appreciable effects on the ground water table level in the test area.

Baseline Well Levels

Fig. 5 is a plot of the baseline well water levels taken during the duration of the experimental test pits for sanitary landfill barrier materials. The hydraulic "tilt" of the water tables can be noted by the consistently higher levels of Well B (west) with respect to Well C (east).

Exhibit F

WB Form 920-11
(9-66)

U.S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

30°22'N
91°10'W

DATA SHEET—DAILY VALUES

Station, LSU Ben Hur Farm (16-5620) 21 Feet

Data Daily Precipitation, in Inches Observation Time 9:AM

1971	January	February	March	April	May	June	July	August	September	October	November	December	
1							.02		.05				
2			.70	.43			.08	.05	.15				
3			.15				.01	.03	.36				
4	0.58		.01				.19	.02					
5		.55					.01	.10	.10	.41			
6							.13	.10	.24				
7		1.04	.30		.03								
8	.30	.28				.88	.01		.50				
9					.09	.03		.04	.01				
10			.30				.47		.09		.44		
11	.41				.49	.32							
12	.01	1.06			1.62				.39				
13	.01	.01	.01		.10		.01	.02	.01				
14													
15			.04			.06			.01				
16						.04			1.34				
17				.04		.08	+	.57	1.74	1.32			
18													
19			1.64								.31		
20		.23	.01	.23		.09			.78				
21		.86				.18	1.19						
22			.03			.74	.58						
23			.01	.04		.23		.15	.31		.01		
24							.35	.30					
25						.03	.61	1.11					
26		.50					.08	.07					
27		.06				.17	.68		1.15				
28					.63		.74						
29			2.12				1.44				2.08		
30						.12	.20						
31							.04	.03					
Sums	1.31	4.59	5.32	0.74	2.96	2.97	7.04	2.59	7.23	1.73	2.84		
Means *	4.06	6.14	3.70	3.75	3.92	3.90	6.14	4.74	3.24	3.36	2.90	4.90	

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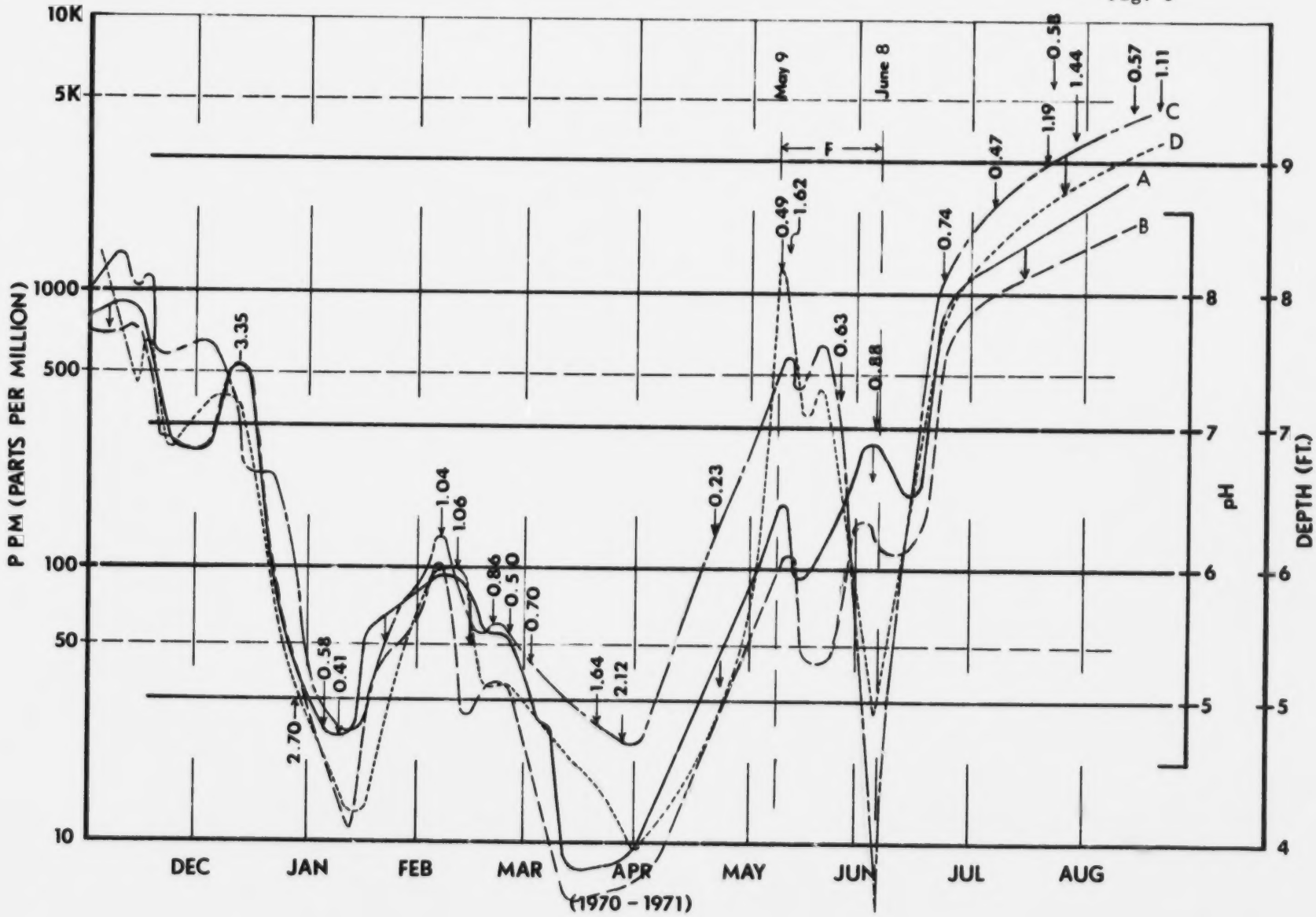
* March 1963 - December 1970

TEST WELL Baseline Wells A-B-C-D

MATERIAL TESTED

Fig. 5



The two north wells (A and B) are consistently higher in level than the two south wells (C and D). This would indicate that throughout the test period, the movement of ground water (i.e., direction of flow) was generally southeasterly. All of the leachate sampling wells (those labeled with the letter *E*) located outside the test pits were drilled within one foot of the vertical plastic (PVC) lined test cell walls and should have been contaminated by any leachate escaping from the cells, since the water table movement (hence, leachate migration) was in this direction. The plot of the data for each of these cells indicates this, where applicable.

The exception to this flow pattern (May 9) and the resultant behavior of the water tables were influenced by the attempt by the research team to assist nature by irrigating the test site from the municipal water supply. More than 225,000 gallons of tap water were delivered to the site through a series of trenches dug at the periphery of the plot, and through three cross-linking trenches subdividing the area into four equal irrigation plots, each of which enclosed three test pits (Exhibit G). This effort, in addition to the rainfall occurring between May 12 and June 8, eventually caused the peak rises in wells C and D. It is not known why wells A and B did not reflect a similar rise. It was observed, however, that the south end of the plot absorbed the greater share of the water, apparently due to some anomally in the soil characteristics or an underground (near surface) strata fault.

None of the test pit interiors showed an increase in water level, which eliminates them as absorbers, assuming (or possibly, confirming) that the barriers and liners did not permit influx of liquids. Flooding of the area was discontinued on June 8 because of the expense ($113 for water) and because the south end of the plot was not being helped as far as leachate collection was concerned. There was also the fact that considerable dilution of any collectable leachate would defeat the purpose of chemical analysis.

Significant rainfall occurrences are indicated along the well level curves to assist in rationalizing the behavior of the curves. As noted before, in this report, the level of the Mississippi River less than one mile away did not influence (certainly not directly) the ground water at the test area levels, as indicated by correlating well level data (Fig. 5) with the river stage data (Exhibit H).

Exhibit H

WB Form 920-11
(9-66)

U.S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

DATA SHEET—DAILY VALUES

Station, Mississippi River Stage - Port Allen, Louisiana

Data, ----------

1971	January	February	March	April	May	June	July	August	September	October	November	December
1	18.4	15.5	24.8	24.6	11.8	19.4	11.6	10.8				
2	19.0	15.4	25.7	24.0	11.6	18.4	11.2	10.7				
3	19.1	15.0	26.7	23.4	11.5	17.4	10.5	10.4				
4	19.8	14.7	27.3	22.8	11.4	16.3	10.1	10.1				
5	20.0	14.7	27.6	22.2	12.0	15.2	9.8	9.8				
6	20.1	14.4	28.1	21.5	12.0	14.4	9.8	9.6				
7	20.2	14.6	28.6	20.7	12.1	13.5	9.7	9.4				
8	20.0	14.5	28.9	19.9	12.4	13.0	9.5	9.6				
9	19.9	14.2	29.2	.2	12.5	12.9	9.0	10.0				
10	19.5	13.8	29.6	18.5	12.4	12.8	8.9	10.1				
11	18.8	13.4	29.8	18.0	12.5	12.8	8.8	10.4				
12	18.2	13.0	29.9	17.4	12.9	12.6	8.4	10.4				
13	17.9	13.4	30.2	17.0	13.8	12.6	8.0	10.5				
14	17.7	13.5	30.6	16.8	14.0	12.4	7.4	10.4				
15	17.7	14.6	30.6	16.4	14.3	12.2	7.0	10.7				
16	17.9	16.0	30.5	16.2	14.7	12.2	7.0	10.8				
17	18.2	16.8	30.6	15.8	15.5	12.2	6.8	11.0				
18	18.3	19.0	30.2	15.5	16.5	11.9	6.7	11.1				
19	18.6	20.2	30.4	15.0	17.8	11.8	6.9	10.4				
20	18.7	21.0	30.1	14.9	18.8	11.5	7.4	10.0				
21	18.7	21.5	29.7	14.5	19.9	11.4	8.0	9.5				
22	18.6	22.0	29.3	14.2	20.6	11.4	8.4	8.7				
23	18.5	22.1	29.0	14.0	21.2	11.4	8.8	8.2				
24	18.0	22.1	28.7	13.6	22.0	11.9	9.4	8.0				
25	17.7	22.3	28.2	13.3	22.3	12.4	9.6	7.5				
26	17.4	22.6	27.9	13.0	22.4	12.7	9.6	7.2				
27	17.2	23.4	27.4	13.0	22.5	12.8	9.7	7.0				
28	16.8	24.3	27.1	12.6	22.2	12.9	9.8	6.8				
29	16.4		26.6	12.3	21.8	12.8	10.0	6.8				
30	16.2		26.0	12.2	21.2	12.2	10.4	7.0				
31	15.8		25.4		20.3		10.8	7.6				
Sums												
Means												

USCOMM-WB-DC

PERMEABILITY TESTING

When a substance permeates a barrier, the rate of permeation can be expressed by parameters which may be characteristic of the barrier. The general concept of the ease with which a permeant passes through a barrier is often referred to as *permeability*. The general term *permeability* does not refer, however, to the mechanism of the permeation process, and in the literature, the rates of transmission are cited in many different units; for example, the total rate of transmission [(amount of penetrant)/(time)]; the rate of transmission per unit area [(amount of penetrant)/(area) (time)]; the rate of transmission per unit area and unit barrier thickness [(amount of penetrant) (film thickness)/(area (time)]; and the rate of transmission per unit area, unit thickness, and unit driving force.

All of these terms are included under the general term *permeability*. For the purpose of this discussion, the amount of water and/or leachate moving through a barrier in a unit time, unit area, and unit pressure gradient is defined as the permeability, since this definition is the most accepted one in the literature. It should be noted that the term is not normalized for film thickness, but is directly related to the thickness. When data is reported, therefore, some measure of this will be included.

From a practical standpoint, the leachate and/or water passage through the sealant in a given time will be reduced to half of the original value by doubling the thickness of the barrier under the same driving pressure gradient. This relationship is true for all leachates which do not interact with the sealant, and, in the systems under study, held for the majority of solutes.

All organic materials present in the landfill will be of significantly higher molecular weight than water. The size of these species, therefore, will be large, and if they do not interact with the sealant, they will permeate the barrier much more slowly than water. Only in those cases where the organic leachate has a very high solubility in the barrier matrix will it become a potential

problem. The materials selected were screened, with two typical organic materials anticipated to represent what may be present in the test sites. These solutes were sugar (molecular weight of approximately 300) and an alcohol (molecular weight of approximately 75).

It should be remembered that all of the sealant materials selected should be impermeable to inorganic species, except possibly some of the clays (such as bentonite), which could undergo ion exchange. This process is slow in relation to the lifetime of the landfill. Tests were conducted in the laboratory to confirm this thesis.

Bacteria and possible viruses are of such gross size, in comparison with the previously itemized leachates, that they should be completely retained within the landfill.

In consideration of these facts, several permeability test cells were designed during the study period, in which each of the 28 sealant materials selected was subjected to a pressure head of 200 pounds per square inch (psi), in order to accelerate the flow of liquid (H_2O) through the sample. The throughput for each sample was recorded over the period of time required to establish a stable flow rate. The output was then converted to an equivalent flow rate at an arbitrary five-foot head, which might be possible in a typical landfill. Additional testing was performed to determine chemical activity (inertness) of the materials upon exposure to some of the potent compounds expected from garbage leachate and certain soil conditions.

Additional permeability tests under static low-pressure heads were performed in the laboratory to determine if, in fact, that high-pressure exposure of the sample materials might not misrepresent the permeability; i.e., instead of accelerating the normal flow through the material, cause the flow to be restricted because of the material compaction due to exposure to more than the normal, expected pressure heads. In some cases, this was found to be true.

All compounds were screened for biodegradability prior to permeability testing. Samples showing promise from this screening were then tested by measuring the water transported across a two-inch barrier, under a constant pressure head. In some cases, it was advantageous to form this barrier by mixing with soil.

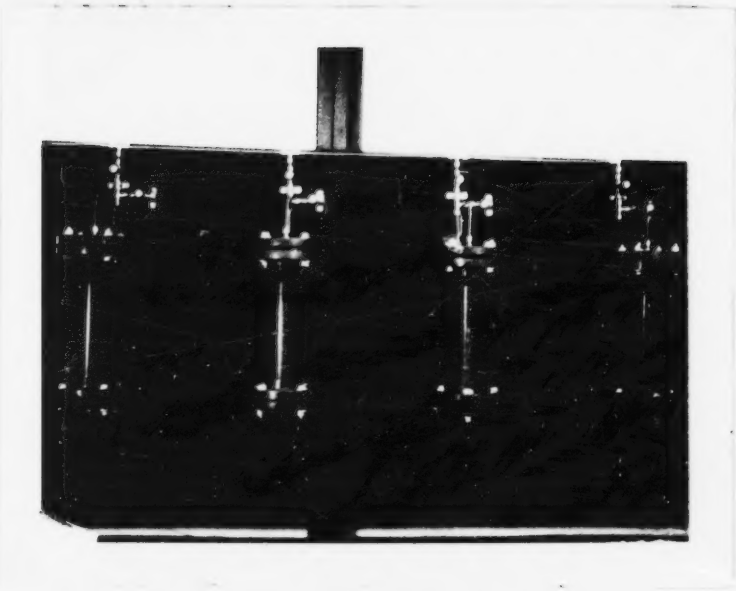
The permeability test used in the laboratory was a modification of the method reported by Mannion and Porter in their work on soil sealing in desalination by-product brine ponds [6].

Four permeability test cells were constructed of two-inch, Schedule-80 PVC pipe, and flanged at both ends (Exhibit I). The bottom flange was machined-out, and a two-inch porous, stainless-steel disc was inserted. One-fourth-inch outlet and inlet fittings were installed on the top and bottom flanges. The top flange was connected to a N_2 pressure source, and tubing was run from the bottom fitting to a graduated buret. With this setup, water pressures could be varied from a few inches to more than 400 feet of effective pressure head (200 psi = 460 feet of water).

The soil used in all permeability tests was obtained from the vicinity of the Baton Rouge field test sites. It was dried, ground in a mortar and pestle, and screened through an 18-mesh screen. For testing, the bottom flange in the cell was put in place, and one inch of washed, dry sand was placed on top of the sand, and tamped lightly with a rod slightly smaller than the diameter of the cell.

Exhibit I

CELLS USED FOR PERMEABILITY TESTS



If the sealant was to be mixed with the soil, this was done on a dry-weight basis before the mixture was added to the cells. If a surface application was being used, the sealant material was applied to the surface of the soil after being added to the cells. The application method used was determined by its physical properties and the way it would be best applied under field conditions. In some cases, more than one method was used. Various combinations of each compound were used to determine the minimum amount needed for effective sealing. Using these methods, the absolute permeation rate of water through sealed soil could not be determined, but the likely candidates for soil sealing could be rapidly screened for use in further testing under actual field conditions.

The pressure driving force was chosen to simulate the worst possible conditions which might occur in the field. There was a problem with compaction of the soil support and sealant material as a function of time and pressure; the reported results were the *highest* permeation rates measured under all test conditions.

Table II indicates the throughput of materials selected for possible field testing. Although some of the materials listed were found to be biodegradable in varying degrees, they were selected to determine the effect on the useful life of the materials as a sealant in the event the project were continued beyond the original two-year grant period.

Table II

THROUGHPUT OF MATERIALS

Material	Class	Degradability	Transport $g/cm^2 sec$
Asphalt	Commercial building material	Stable	10^{-7}
Tar paper	Commercial building material	Stable	10^{-7}
Dow Latex 4624	Organic waste product	Moderately biodegradable	2×10^{-7}
Uniroyal rubber polymer; waste product	Organic waste product	Highly biodegradable	10^{-7}
Styrene tars	Organic waste product	Biodegradable	10^{-7}
Armour cationic asphalt-- emulsion	Commercial water sealant	Slightly biodegradable	3×10^{-8}
PVC film 6 mil	Commercial vapor barrier	Extremely stable	10^{-9}
Kaiser red mud slurry	Clay	Stable	1×10^{-7}
Bentonite	Clay	Stable	10^{-8}

The following paragraphs describe the commercial and industrial waste products tested for permeability.

Commercial Products

Armour Cationic Asphalt Emulsion

This emulsion, known commercially as pondseal, is used primarily for sealing soil in reservoirs and ponds to minimize seepage. It is a formulated cationic emulsion, consisting of chemical emulsifiers,

asphalt, and water. Each asphalt droplet (when added to the pond water) carries a positive charge, which is attracted to negatively charged soil particles as the emulsion permeates the sod. This action causes an impermeable film to form at the soil interface. Some simple soil surface tests indicated that as little as 15 fluid ounces per square foot will effect a near-zero seepage, discounting evaporation losses. This product costs $.65 per gallon (May 1970) in 55-gallon-drum quantities.

Enjay Chemical Company CLTA Polymer

This product consists essentially of C-5 and C-6 olefins and diolefins. The flash point is 230°F., and the API specific gravity is 7.5 to 12.5 at 60°F. Its boiling range is above 600°F. The molecular weight is approximately 1,000, and it does not become brittle with age. This polymer was applied as a surface coat and was allowed to soak into the soil for 24 hours. No flow occurred at low pressures, but at higher pressures, considerable flow occurred. The cost of this material is approximately $.25 per gallon. It is classified as chemically inert.

Enjay Chemical Company S-2 Tar

S-2 Tar comes from the bottom of the cracking column, and is used to feed coke to increase burning. Roofers also buy it and strip it to make tar. It is a mixture of aromatics, with a flash point above 230°F., API gravity of -2.5 to 0.5 at 60°F., and a fairly low viscosity. It was applied to the soil surface and was allowed to soak in for 24 hours. Throughput was very fast, even at low pressures; and for this reason, the material was rejected.

Dow Experimental Latex CX 4624

This product is a 50 percent solids content Saran latex, with a high concentration of wetting agents. It was applied to the surface of the soil and was allowed to dry and soak in. It formed a good, fairly resilient film that had good soil-sealing capabilities.

No firm cost figures were available, but they were expected to be competitive with those of other commercial sealants.

Dow 464 Saran Latex

This is an off-grade resin and is expected to be much less expensive than the CX 4624 latex. It has a 50 percent solids content and has been used as a vapor barrier on air strips. It formed a good film on the surface of the soil and gave good results in soil sealing tests, even at high pressures.

Foster Grant Polystyrene Lome 4

This is an inexpensive polystyrene product with a low molecular weight. A 20 percent solution was made in benzene and applied as a top coat, mixed with the top layer of soil, and on filter paper, placed beneath the soil layer. All of these methods failed, even at low pressures, and work was not continued on this product. In addition, the high cost of solvent would probably make the product uneconomical for large-scale soil sealing.

Baroid Bentonite Clay

This is a clay used locally in drilling muds. It is mined in Clayspur, Wyoming, and has been used successfully for some time in soil-sealing applications. Bentonite consists largely of montmonillonite clay. It swells considerably in water, displaying thixotropy and other colloidal properties. Different concentrations and pressures were used, and all gave excellent results. Because of its low cost, ease of application, and good soil-sealing capabilities, this compound is one of the best commercial compounds tested. Both surface coating and mixing with the soil gave good results.

Waste Products

Hercules, Inc., LCA Resin

This product is an amorphous polypropylene resin containing about 10 percent high-boiling kerosene. The melt viscosity can be reduced by the further addition of kerosene, but this was not done for this study. Instead, the resin was heated until molten, and then applied as a surface coat, mixed with the top layer of soil, coated on filter paper, and placed beneath the soil layer. In all cases, there was no flow at all until the higher pressures broke the layers. Except for difficulty in applications under field conditions, this seemed to be a good candidate for soil sealing, when used under the proper conditions.

Ethyl Corporation C^{20+} Alcohol

This waste product is a white, waxy-looking compound containing about two-thirds higher alcohols and one-third paraffins. It has a low melting point (120°F.) and a high flash point (445°F.). It was tested as a top coating, mixed with the top layer, and as a coating on filter paper placed below the soil layer. No water came through in any test as long as the layer was intact. At high pressures, the layer broke in all cases. This compound is a very good soil sealant, but could fail under field conditions.

Foster Grant Waste Styrene Tars

This is a very viscous, black, tarry substance containing a precipitate of elemental sulphur. When allowed to stand on the soil surface, it is slowly absorbed and forms a rather impermeable layer. For testing, it was applied to the surface of the soil and was allowed to absorb into the top layer for 24 hours. Sealing was not very good at high pressures, but sealing was complete at low pressures.

Kaiser Red Mud Slurry

This waste in a slurry form is usually discharged locally into the Mississippi River. It is the inert, insoluble residue obtained from bauxite in the Bayer Process, after the caustic extractions of all available alumina. It contains a large amount of the oxides of iron, as well as the oxides of silicon, aluminum, titanium, and calcium. This slurry was poured carefully on the surface of the soil and allowed to settle. It does a good job of sealing the soil, even under high pressure.

Pressure Effects on Permeability

Under normal field conditions found in sanitary landfill operations, an effective waterhead of five feet or more will rarely be reached. Ideally, any laboratory testing of the effects of soil-sealing candidate materials should attempt to duplicate these conditions as closely as possible. The Falling Head Permeability Test and the Constant Head Permeability Test (ASTMD-2434-65T) are the methods generally accepted by hydrologists for measuring soil permeation. These methods are acceptable in cases where the permeability is in the range of 10^{-3} to 10^{-6} cm sec^{-1}. If a material has any effectiveness as a soil sealant, the permeability will be below the range of the standard test methods. An alternative method was employed, therefore, for the testing under this project.

As stated previously, the effects of the use of high pressure on soil compaction was noted. In the first series of experiments on soil sealing, a decrease in water permeability occurred during the period of the runs. A series of tests were then made to determine the effect of high pressure on the permeability of the standard soil alone. Samples of the same soil treated in the manner previously described were loaded in the test cells. Pressure was applied, and the water permeability was measured as a function of time. The results are indicated in Fig. 6.

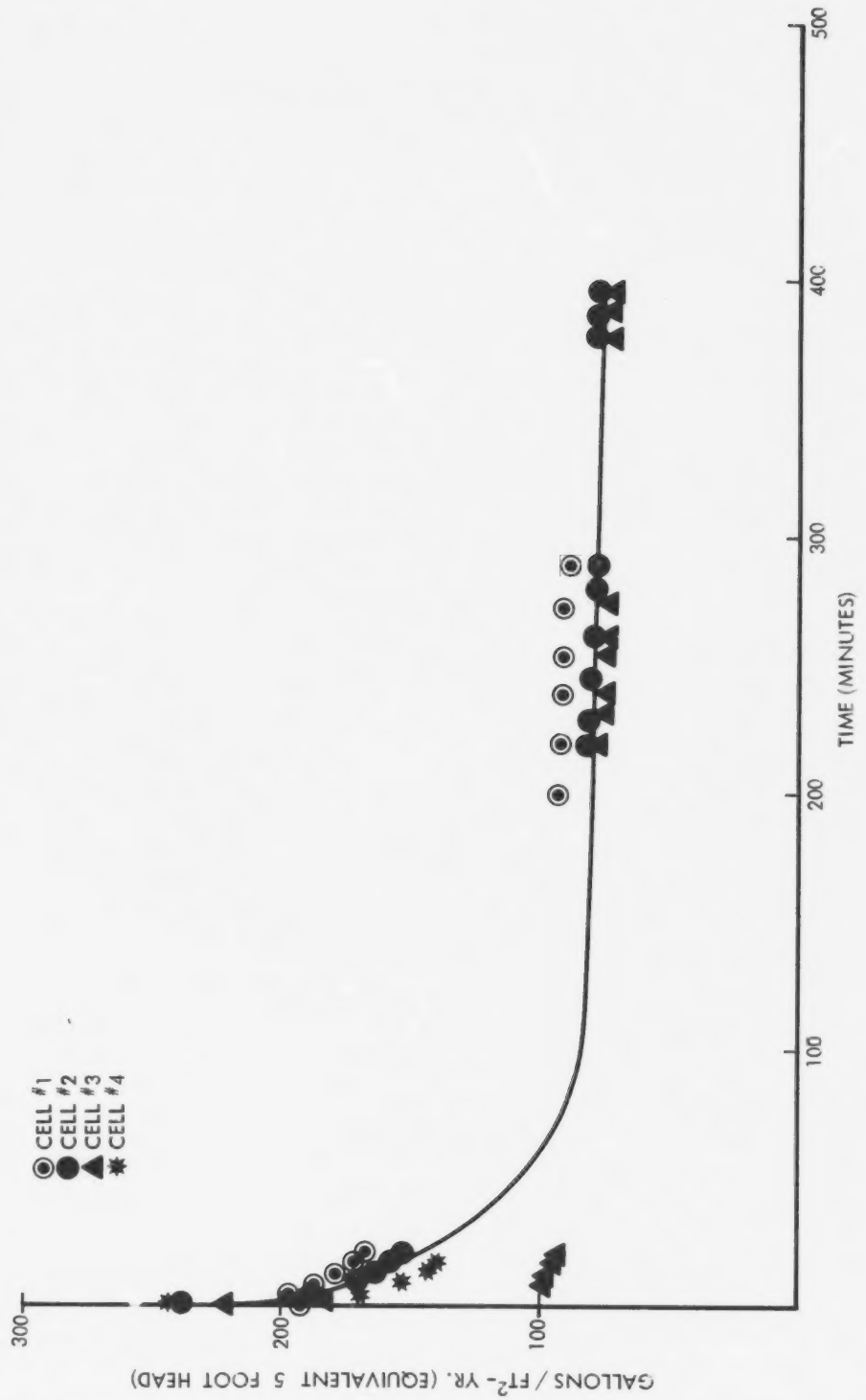


Fig. 6 EFFECT OF HIGH PRESSURE (200 psi) ON PERMEABILITY OF SOIL

The effects of pressure on the permeability of the soil are readily evident in this chart. Throughput after two hours is less than half of the value at the beginning of the tests. Consequently, all readings on the sealing effectiveness of candidate compounds were taken as soon as possible when high pressures were used. Also, whenever possible, stepwise increases in pressure were used, and permeability measurements were taken at the lowest pressure possible.

Pressure also had an effect on the integrity of the soil sealant under test. This was found only for some of the compounds tested, when used as a surface treatment, and was found only at high pressures. One of the compounds tested, Foster Grant waste styrene tars, is an example of this. At low pressures (less than 25 psi), virtually no throughput was observed. At 50 psi, throughput was less than one gal./ft.^{2}/yr. at an equivalent five-foot waterhead, and at 200 psi, throughput was greater than 60 gal./ft.^{2}/yr. at an equivalent five-foot head. Physical inspection of the sample indicated that the compound, which is like a viscous tar, had been pushed into the soil at high pressure and had lost some of its sealing properties in the process. Other compounds, such as Hercules LCA resin, actually broke at high pressures and allowed water to channel through the cracks into the soil below. This did not occur at pressures less than 25 psi.

PRELIMINARY TESTING UNDER SIMULATED CONDITIONS

The 28 products selected as being potentially useful as sealants were screened individually, and the list was reduced, for preliminary test purposes, to five commercial products and five industrial waste materials, as indicated below:

Commercial Products	Waste Materials
Armour Pondseal	Foster Grant Styrene Tars
Dow Chemical 4624	Uniroyal Rubber Floc
Asphalt	Ethyl Alcohol C^{20+}
Dow 464	Hercules LCA Resin
Bentonite	Kaiser Red Mud

Each of these products (with the exception of Uniroyal rubber floc and asphalt tar paper) was tested in 10 vertical columns, measuring 6" x 4', designed to simulate elemental core samples from a sanitary landfill. (Construction of the columns is illustrated in Fig. 7, and a reproduction of two of these columns is shown in Exhibit J.)

Most of the materials were tested as a mixture with local soil to determine the minimum amount of material needed to effect the seal. From these, and from the tests previously described, five mixes were selected initially for testing in the 10 test columns. The five mixes (by weight) were as follows:

1. 10 percent bentonite and 90 percent local soil
2. 10 percent bentonite and 90 percent sand
3. 10 percent red mud slurry (bauxite residue) from Kaiser Aluminum Company, and 90 percent soil
4. 10 percent 4624 latex (from Dow Chemical) and 90 percent soil
5. 30 percent cationic asphalt emulsion (from Armour) and 70 percent soil

Each of these five materials was thoroughly mixed with soil, and water was added until the mix had a consistency similar to that of thick chocolate cake icing. The mix was then applied in each cell at the refuse/soil interface in layers approximately one-inch thick.

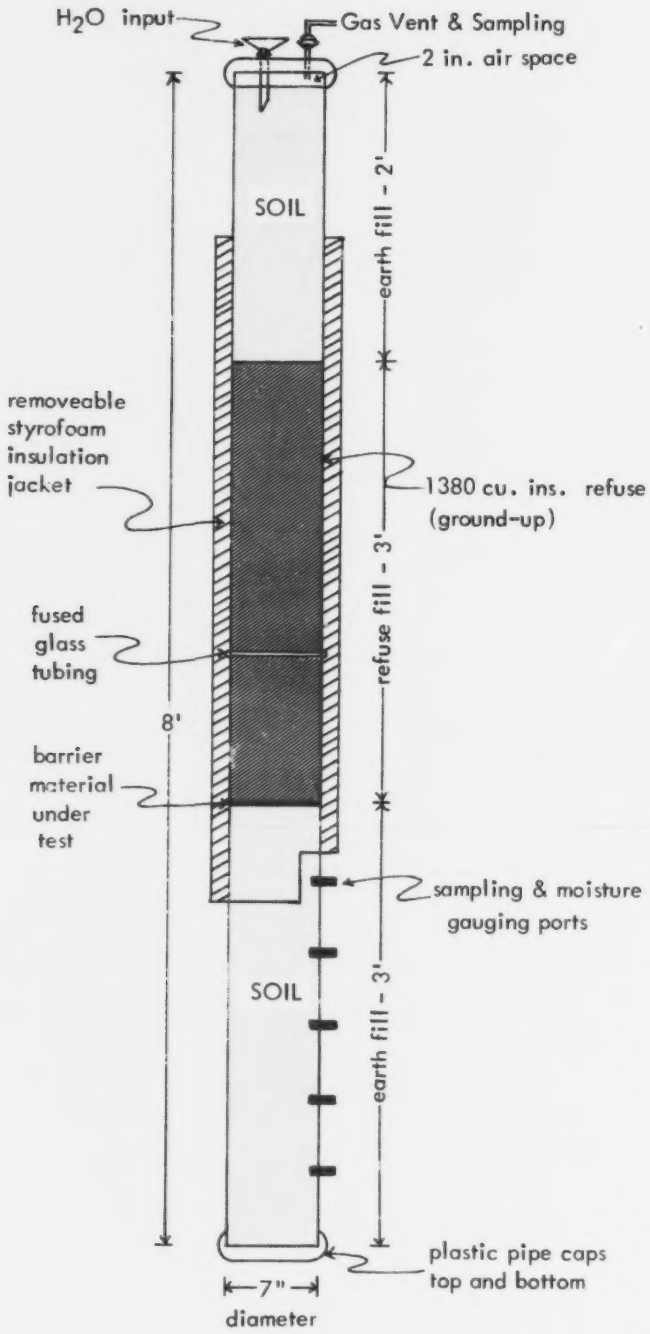
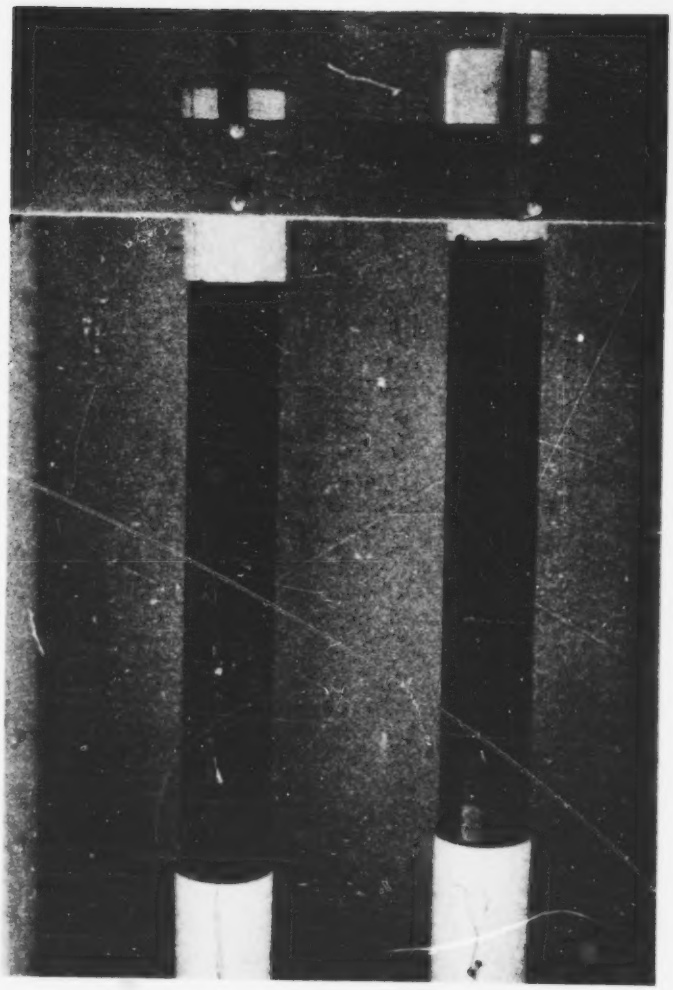


Fig. 7 CROSS SECTION OF PRELIMINARY TEST COLUMN CONSTRUCTION

Exhibit J

TWO OF THE TEN PRELIMINARY TEST COLUMNS



The refuse mix (166 lb.) was synthesized in the following proportions:

118 lb.	Shredded paper and water in the ratio of one part paper to six parts water by weight. This was necessary to reduce the volume of paper required.
13.5 lb.	Metal turnings (95 percent iron, 3 percent stainless, 1.5 percent aluminum, 0.5 percent brass
6.0 lb.	Sawdust (wood)
7.5 lb.	Mixture of 4 lb. leaves; 2 lb. grass; 1.5 lb. hedge clippings; thoroughly ground in a food disposal unit
21.0 lb.	Food waste from cafeteria, ground in food disposal unit

The final mix, including the water added, had a bulk density of 47 lb. per cubic foot. All of the materials listed above were thoroughly mixed in a 1/3-cubic-yard concrete mixer (Exhibit K). Each cell was subsequently charged (April 15, 1970) with an average of 27.5 lb. of this refuse mix. Some liquid was lost during the actual placement of the materials in the cells. The barrier layer was also displaced to an unknown degree, due to the soggy nature of the refuse mix and the manner in which it was necessarily deposited in the four-foot length of glass tubing.

Each test cell was equipped with a thermistor temperature probe inserted through the PVC column wall. This proved to be of no value, since the styrofoam jackets surrounding the glass tubing were not sufficient insulation to contain any temperature rise due to waste decomposition. Evidently, the relatively small volume of waste generated heat much slower than the rate of heat loss to the environ. Actual continuous strip chart recordings reflected the daily ambient temperature cycle. Temperature data was only academic and had little to do with the purpose of the test.

Exhibit K

SYNTHESIZING OF REFUSE MIX

The moisture-sensing probes were simple stainless steel electrodes embedded in the sand substrate beneath the barrier test layer. Relative moisture readings were obtained indirectly by measuring the electrical impedence between electrodes (resistance to alternating current flow) with an AC impedence bridge. As the moisture increased, the impedence (resistance) dropped, and vice-versa. A log of these readings was made to plot the changes in moisture content of the sand substrate for each cell.

The erratic nature of the moisture readings soon led to the discovery that channeling of leachate between the glass wall and the test material (periphery) interface was not reflecting a true picture of the performance of the material. Although the test columns were rigidly supported, thermal expansion and contractions caused an otherwise dry seal to fracture, thereby allowing channeling of the liquids above the barrier material downward into the sand substrate. A material such as bentonite, which remains fairly moist, provided a better seal to the glass surface than one which solidified (such as the Alcohol C^{20+} waste or the LCA resin material) because of the resilience of the material.

These cells were monitored for two months, with the expectation that the leakage would stabilize. Since this did not occur, it was decided to duplicate the test for all 10 materials chosen for the field test experiments. On June 12, 1970, the original five test columns were dismantled and recharged with a "fresh" synthesized garbage mix of the following composition:

128 lb.	Paper pulp (104 lb. of water; 24 lb. of paper)
24 lb.	Food waste from cafeteria
15 lb.	Metal turnings
16 lb.	Wood waste (sawdust)
9 lb.	Green garden trimmings
192 lb.	Total net weight (bulk density 700 lb. per cubic yard)

All 10 cells were charged, using extreme care in placement of the refuse within the cells to prevent damage to the barrier materials under test. Extra barrier material (filets) was placed in contact with the walls of the glass columns in an attempt to prevent the previous experience with channeling of leachate at the wall interface.

The results of these tests were inconclusive, since physical problems involving channeling and rupturing of the barrier materials contributed an undetermined amount of leakage through the test column cells. Such small-scale testing seems to be impractical, due to lack of an effective glass test material-sealing technique to prevent channeling of the leachate resulting from thermal contractions of the test material. No problem was encountered with the asphalt, however, since it remained resilient, as expected, over normal temperature ranges.

ANALYSIS OF DATA FOR BASELINE AND CELL MONITORING WELLS

Expression of Results

The avoidance of ambiguity in reporting results is a genuine problem for chemists communicating with other disciplines. One frequently used approach is the use of "significant figures," indicating that all of the digits in a reported result are expected to be definitely known. This must take into consideration the accuracy of the work and the relative merits of the analytical procedure, as well as the current ability of any discipline to interpret the results and to what degree the results are meaningful to the overall work performed.

This section of the report generally adheres to the standard reporting procedures. To completely define the expression of results for this study, a brief summary is included below for each parameter reported:

pH units were read to the second decimal place, but reported only to the first decimal; e.g., 7.18 is recorded as 7.2.

Biochemical Oxygen Demand (BOD) results below 10 were reported to the nearest whole number. Results between 10 and 100 were rounded as follows: 13 was rounded to 15; 72 was rounded to 70. The same rule was followed for higher values.

Chemical Oxygen Demand (COD) results were reported in the same manner as the BOD results.

Residue values were rounded to the nearest significant number.

The *anions* (chloride, sulfate, nitrate, and phosphate) were reported only to the first significant decimal place.

Description of Analytical Procedures

The 13th Edition of *Standard Methods for the Examination of Water and Wastewater* was used as a reference for all aqueous analyses.

The pH values were determined electrometrically, and standard solutions were used for calibration purposes.

The biochemical oxygen demand (BOD) results were obtained by using the procedures outlined in *Standard Methods*, for polluted waters. The addition of sewage organisms to the standard dilution water was not necessary, since the soil microorganisms provided the necessary biological population for oxidation of the organic matter in the samples. Parallel sets of samples used on numerous occasions indicated that the addition of sewage seed did not affect the BOD results after the seed correction factor was applied.

Chemical oxygen demand (COD) was determined by the dichromate reflux method, using silver sulfate as a catalyst. The samples analyzed did not contain interfering halogens.

The total residue determinations were performed in accordance with *Standard Methods*. Total suspended residue (nonfilterable residue) was obtained directly by passing an appropriate volume of sample through a weighed glass filter.

Chloride was determined by the mercuric nitrate procedure, employing xylene cyanol FF. Sulfate was determined by the turbidimetric method with a spectrophotometer. The brucine method was selected for the determination of nitrate. The phosphate values all represent total dissolved and suspended orthophosphate, without preliminary filtration, hydrolysis, or digestion of the sample. The stannous chloride method was used.

Baseline Monitoring Wells

Before the 12 field test cells were excavated, ground water samples from baseline monitoring wells (12 feet deep) were analyzed

to establish baseline data for detecting chemical changes in the test area water-table media. Location of the five baseline monitoring wells (A, B, C, D, and E) was shown previously in Fig. 4. The purpose of these wells was to provide data on the naturally occurring levels of acidity or alkalinity (BOD, COD, total residue, suspended residue, chloride, sulfate, nitrate, and phosphate) present in the water table encompassing the area containing the landfill test cells. These data are summarized in tables III, IV, and V, which indicate maximums, minimums, and averages for the values obtained.

Table III indicates that chloride, nitrate, phosphate, total solids, and, probably BOD, are the most useful tools in detecting contamination of leachate from the cells. The low backgrounds established for the months prior to installation of the field test cells provide data for evidence of contamination in both the baseline wells and wells drilled near the site of each cell. Additional analyses, such as COD, nitrites, and ammonia, were added to the weekly chemical review of the test area.

Table IV lists the average values for the baseline monitoring wells, and Table V is a final summary of chemical data for the wells.

Baseline wells A and C were monitored for a two-year period, and wells B, D, and E were sampled for a one-year period.

The project team was disappointed to learn that the water tables for the monitoring wells did not rise, as expected, above the five-foot level. It is believed that the unexpected construction of a municipal drainage canal shortly after the team began monitoring water tables at the test site was partly responsible. This eight-foot deep canal was dredged about 1,000 feet south of the test site and upstream from the normal flow, or migration, of the immediate subsurface water table. It is possible that this canal interrupted and intercepted the pre-canal flow of subsurface water, thus affecting the maximum height of the water table at the test site. Several water table readings were completed prior to construction of the

Table III

SUMMARY OF CHEMICAL DATA FOR BASELINE MONITORING WELLS (Through October 1970)
(mg/l)

Baseline Well[a]	pH	Total Solids	Fixed Solids	Suspended Solids	Fixed Suspended	BOD	Chloride	Sulfate	Nitrate	Phosphate
Well A (10-69/10-70)										
Maximum	7.4	17,380	215	342	36	19.8	9.50	31.5	0.10	1.00
Minimum	6.6	346	51	36	b	2.9	< 0.50	19.3	0.01	0.05
Average	6.8	584	156	74	6	9.1	1.96	26.1	0.06	0.60
No. of Analyses	15.0	15	15	7	7	15.0	10.00	10.0	6.00	11.00
Well B (10-69/10-70)										
Maximum	8.0	3,946	201	93	20	70.0	8.00	25.0	0.52	2.60
Minimum	6.0	129	48	3	2	2.9	4.00	4.7	0.03	0.15
Average	7.3	345	105	48	10	8.2	5.80	13.5	0.15	1.10
No. of Analyses	15.0	15	15	7	7	15.0	9.00	10.0	5.00	12.00
Well C (6-70/10-70)										
Maximum	7.9	1,027	199	235	13	15.0	4.00	35.6	0.51	0.20
Minimum	6.8	433	98	7	3	1.0	< 0.50	22.7	0.06	0.00
Average	6.9	597	160	88	6	5.7	1.10	27.6	0.15	0.10
No. of Analyses	12.0	12	12	6	6	10.0	9.00	10.0	6.00	12.00
Well D (6-70/10-70)										
Maximum	7.8	638	187	89	11	22.0	2.70	51.5	2.50	1.50
Minimum	6.7	388	49	33	b	2.4	< 0.50	30.8	0.08	0.01
Average	6.9	546	147	65	7	7.6	0.64	41.2	0.80	0.30
No. of Analyses	12.0	12	12	6	6	10.0	10.00	9.0	5.00	11.00
Well E (8-70/10-70)										
Maximum	8.0	682	182	54	19	24.0	9.00	22.5	1.40	1.10
Minimum	6.8	247	48	310	42	6.1	< 0.50	13.2	0.01	0.08
Average	7.0	517	135	--	--	8.5	2.60	16.1	0.30	0.50
No. of Analyses	8.0	8	8	4	4	7.0	8.00	9.0	6.00	9.00

[a] Dates of sampling are indicated in parentheses.

[b] not detectable.

NOTE: Maximum values obtained for wells A, B, and C were due to the fact that the wells had just been drilled. Pumping corrected the problem. The high values were not included in the average values. These 15-foot wells extend approximately 8 feet into the water table.

Table IV

AVERAGE VALUES FOR BASELINE MONITORING WELLS (Through October 1970)
(mg/1)

Baseline Well	pH	Total Solids	Fixed Solids	Suspended Solids	Fixed Suspended	BOD	Chloride	Sulfate	Nitrate	Phosphate
A	6.8	584	156	74	6	9.1	1.96	26.1	0.06	0.6
B	7.3	345	105	48	10	8.2	5.80	13.5	0.15	1.1
C	6.9	597	160	88	6	5.7	1.10	27.6	0.15	0.1
D	6.9	546	147	65	7	7.6	0.64	41.2	0.80	0.3
E	7.0	517	135	--	--	8.5	2.60	16.1	0.30	0.5

Table V

SUMMARY OF BASELINE WELL CHEMICAL DATA (For Entire Study Period)
(mg/1)

Baseline Well*	pH	BOD	COD	Total Residue			Suspended Residue			Chloride	Sulfate	Nitrate	Phosphate
				Total	Volatile	Fixed	Total	Volatile	Fixed				
Well A (34)													
Maximum	7.4	45.0	60.0	1,030	455	770	740	440	680	9.0	31.0	0.0	1.00
Minimum	6.6	3.0	8.0	345	50	245	280	50	220	< 1.0	19.0	< 0.1	0.05
Average	7.1	9.0	25.0	600	190	400	510	145	360	< 1.0	26.0	< 0.1	0.70
Well B (29)													
Maximum	8.0	15.0	30.0	740	345	520	500	260	450	8.0	25.0	0.5	1.40
Minimum	6.0	2.0	2.0	130	40	80	140	10	15	< 1.0	4.7	< 0.1	< 0.10
Average	6.8	6.0	15.0	350	130	225	290	130	180	5.0	13.0	< 0.1	0.20
Well C (35)													
Maximum	7.9	55.0	75.0	730	240	560	560	230	490	4.0	36.0	0.5	0.20
Minimum	6.7	1.0	<1.0	180	90	95	160	65	230	<1.0	23.0	0.1	< 0.10
Average	6.9	6.0	15.0	545	160	410	440	140	330	<1.0	27.0	0.2	0.10
Well D (30)													
Maximum	7.8	22.0	55.0	640	190	495	550	210	470	2.7	51.0	3.0	1.50
Minimum	6.6	2.0	5.0	390	45	250	375	30	300	<1.0	31.0	0.1	0.10
Average	6.9	6.5	20.0	535	140	410	490	120	370	<1.0	41.0	1.2	0.30
Well E (25)													
Maximum	8.0	10.0	35.0	590	200	460	505	190	390	2.5	22.0	1.4	1.10
Minimum	6.8	<1.0	2.0	420	80	250	380	45	280	<1.0	13.0	< 0.1	0.10
Average	7.2	5.0	10.5	500	150	360	455	125	330	<1.0	16.0	< 0.1	0.50

*Number in parentheses indicates the number of times the well was sampled.

drainage canal, and these data indicated no river stage influence. Any influence due to high river stage was exerted on the deeper aquifer beneath the test site.

Well A

Well A was located 10 feet east of landfill Cell 12, in which an asphalt roofing felt was evaluated as a sealant. The maximum, minimum, and average values for the chemical parameters selected as pollution indicators are summarized in Table V. Six months after Cell 12 was filled with municipal refuse, Well A samples suddenly contained a heavy, but fine, black, precipitate. Within two weeks, the odor of hydrogen sulfide was prominent, and the dark particulates became larger in size. This well was moderately contaminated for seven months after the first appearance of pollution. During the last month of the study, the sample color changed to a dark tan, and the odor was absent. The pH values were not good indicators during this period, since there was little variation in data. The BOD and COD values were higher, but not high enough for a positive evaluation. Total and volatile solids increased during this interval, but they were not truly definitive, since normal baseline values were obtained approximately every third sampling period. The other parameters yielded values too low for interpretation.

A portion of asphalt felt was introduced into a standard BOD water solution, seeded with organisms from Well A, which was polluted by then. Monthly seeding failed to yield any color or odor, although it was held at 72°F. for six months.

Conclusive evidence of the pollution of Well A from Cell 12 is obtained only from the visual and odorous condition of the samples from this well. This evidence was pronounced.

Well B

Baseline Well B was sampled at two-week intervals for one year (for a total of 29 samples). The data summary in Table V places its characteristics well within the normal pattern developed by baseline wells C, D, and E. There were no chemical or physical parameters to indicate leachate contamination of this well.

Well C

Well C was monitored over a two-year period, with 35 samples being collected at weekly to twice-monthly intervals. The maximum BOD was obtained seven months after the landfill cells were charged This sample was septic in appearance, with odors of hydrogen sulfide and rancidity present for the first time. The pH reached the minimum value, and the BOD reached the maximum value, with an elevated COD concurring. The solid residue was low. This condition did not occur again, even during the wet season, so it must be concluded that this well remained uncontaminated with leachate during the study.

The high values discussed above, and summarized in Table V, for Well C are only slightly above reasonable baseline values.

Well D

Thirty (30) samples were obtained from Well D during a one-year period, at one- to two-week intervals. The maximum BOD was obtained shortly after the well was installed, and was not significant due to the pattern developed by the other wells. Installation created mud and temporarily high solids. The maximum COD was obtained four months after the refuse cells were charged. Since the pH, odor and color, BOD, and solids were normal, the reasonable COD of 55 mg/l is not considered significant. There was only a trace of rainfall on this occasion.

This well falls within the values established for the baseline wells.

Well E

Chemical characteristics of Well E fell within the average baseline summary data. There was no odor or color change during the one year of monitoring. Twenty-five (25) samples were collected at two-week intervals. All parameters indicated that this well received no leachate.

Figures 8, 9, 10, 11, and 12 are plotted graphs summarizing the data obtained for wells A, B, C, D, and E, respectively, concerning pH and water level.

Field Test Cells

Eleven field test cells, each measuring 8' x 8' x 6' (deep), were constructed in the area of the five baseline wells. Before being charged with municipal garbage, the cells were each equipped with two 2-inch PVC pipes centered vertically in each cell. One of the pipes was installed in a small sand-filled trap in the cell bottom, and fitted concentrically with a skirt of PVC film to prevent leachate from channeling to the sampling trap below. The second pipe was used to sample liquids collecting within the cell.

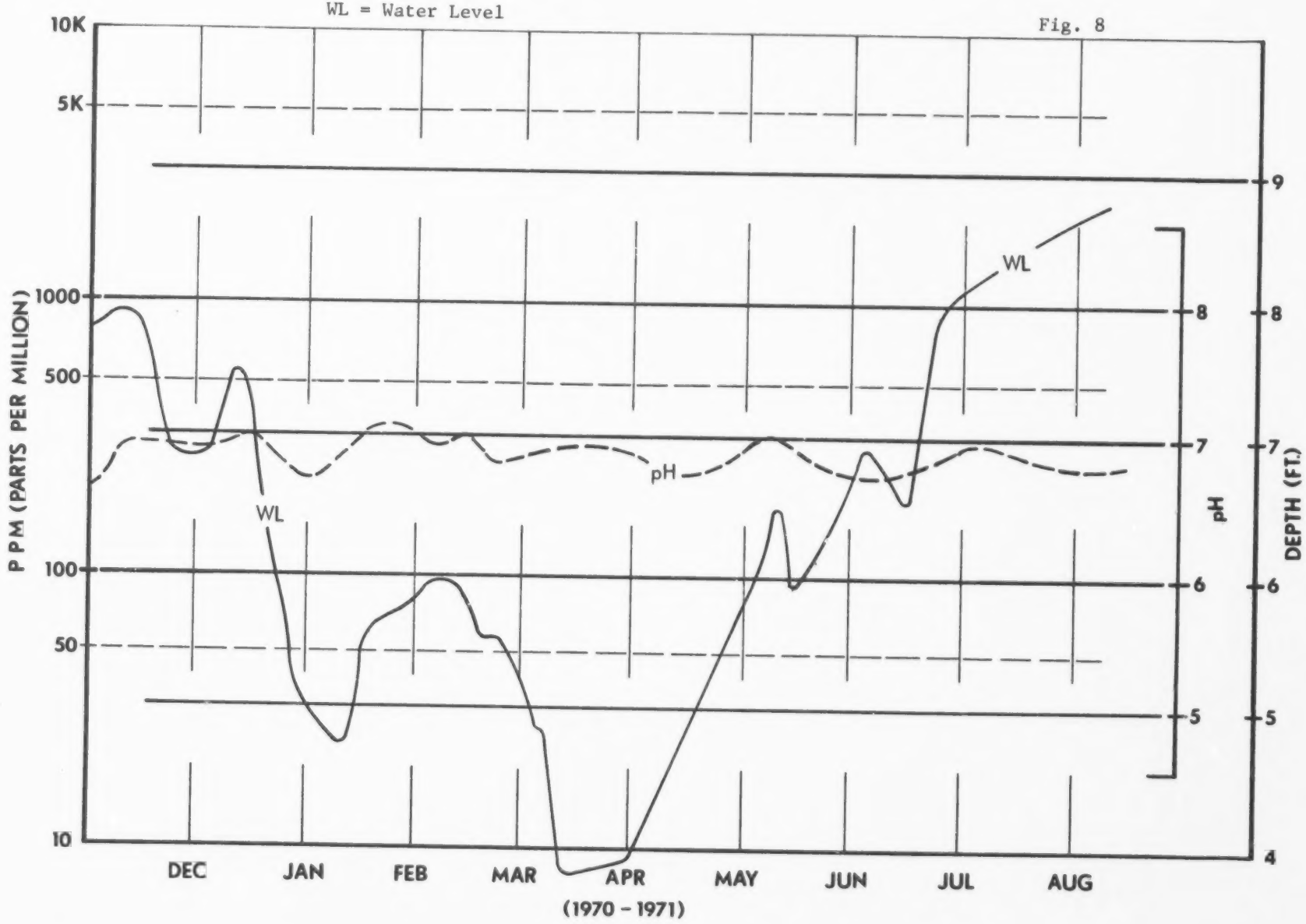
Periodic checking for leachate concentrations in the sampling pipes began on August 27, 1970, and continued, along with the routine monitoring of the original baseline wells. After several weeks had passed and several rainfalls had occurred, it was apparent that no detectable leachate would accumulate in the sampling pipes. The primary reason for this, other than possibly a perfect performance of the sealant materials, was failure of the ground water to rise within the elevation of the sampling pipes and/or the refuse area. Secondly, if leaching through the barrier material was occurring, the amount was being absorbed by the surrounding soil media at a rate too fast to permit accumulation for sampling purposes.

TEST WELL Baseline Well A

MATERIAL TESTED

WL = Water Level

Fig. 8

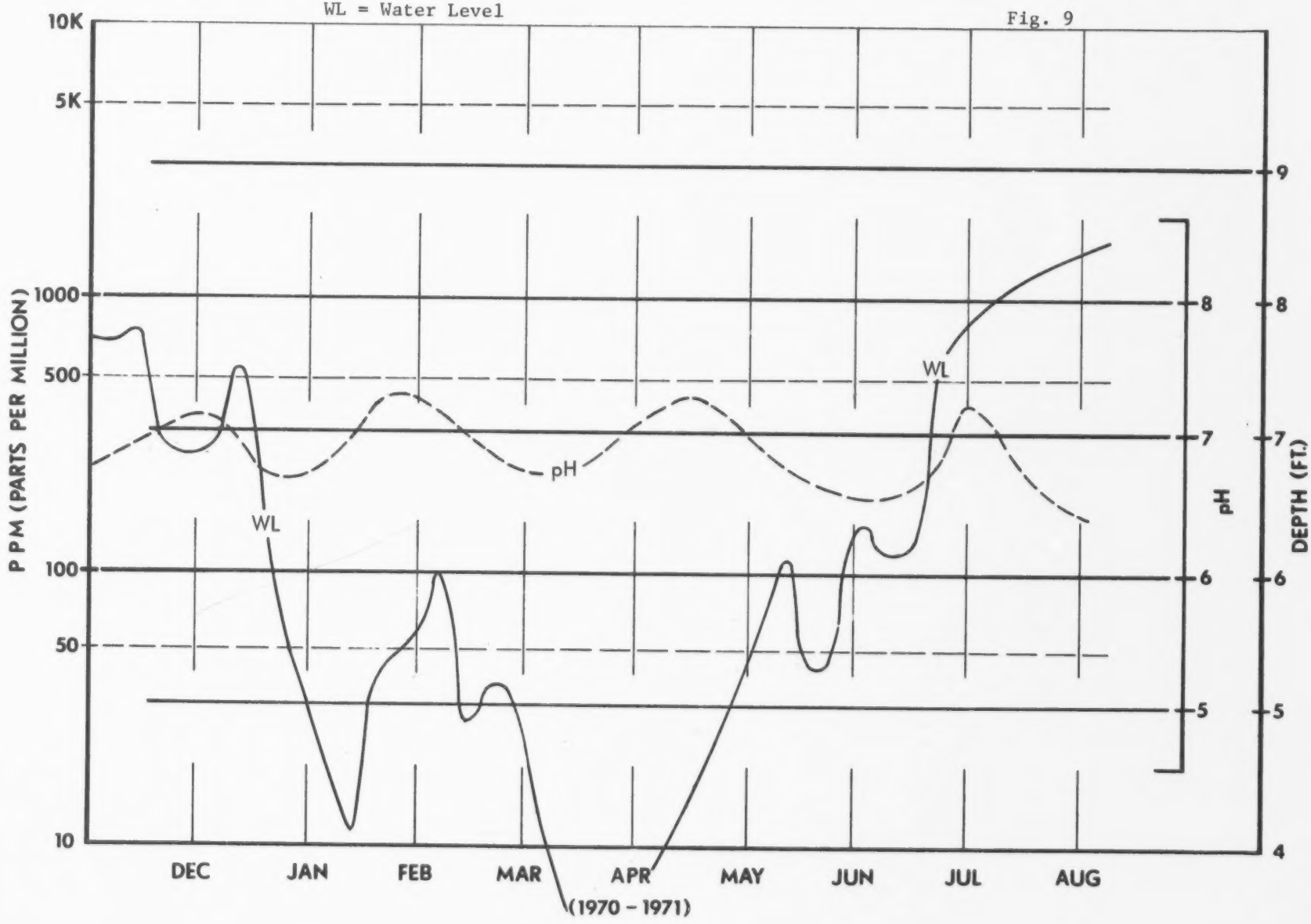


TEST WELL Baseline Well B

MATERIAL TESTED

WL = Water Level

Fig. 9

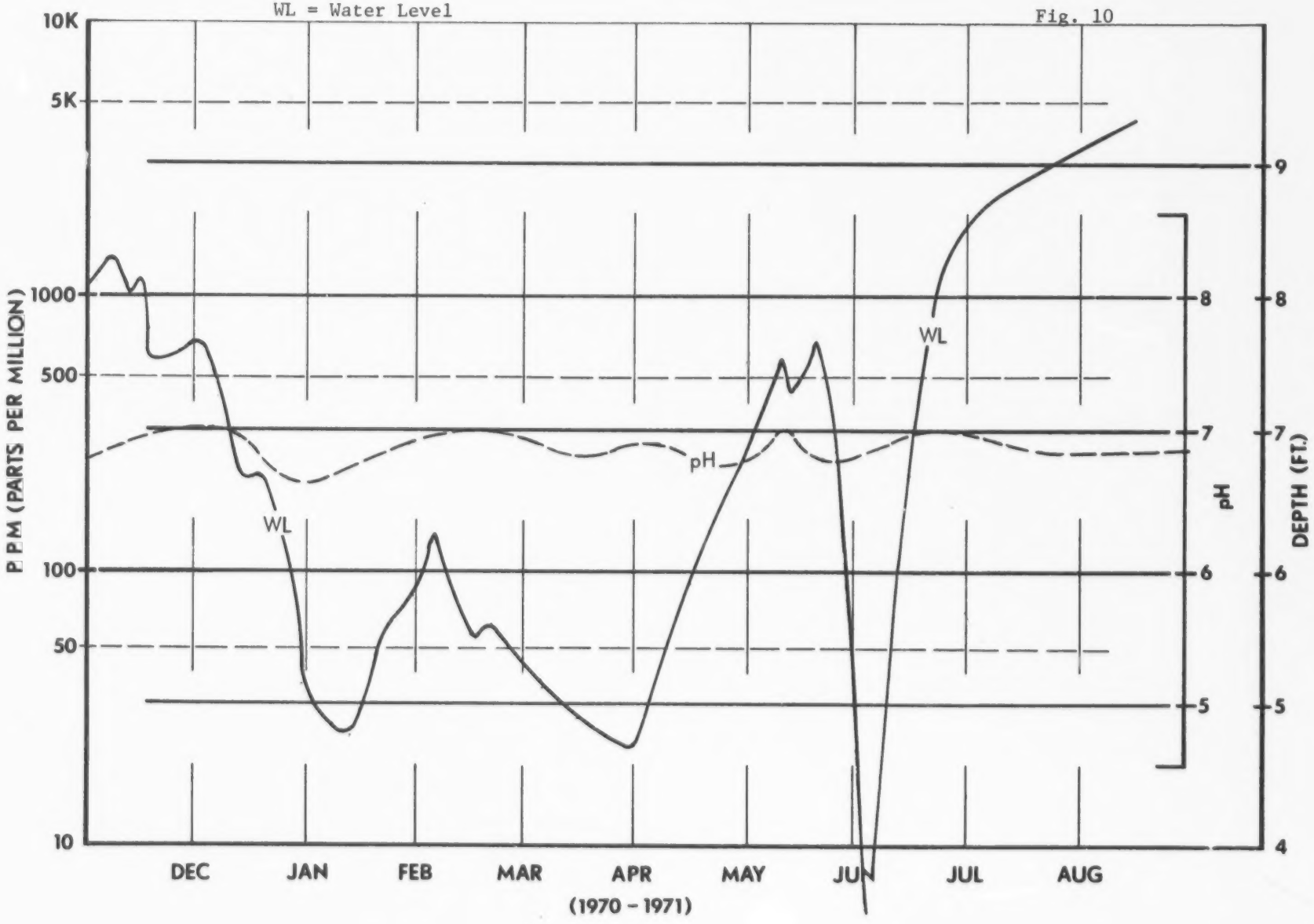


TEST WELL Baseline Well C

MATERIAL TESTED

WL = Water Level

Fig. 10

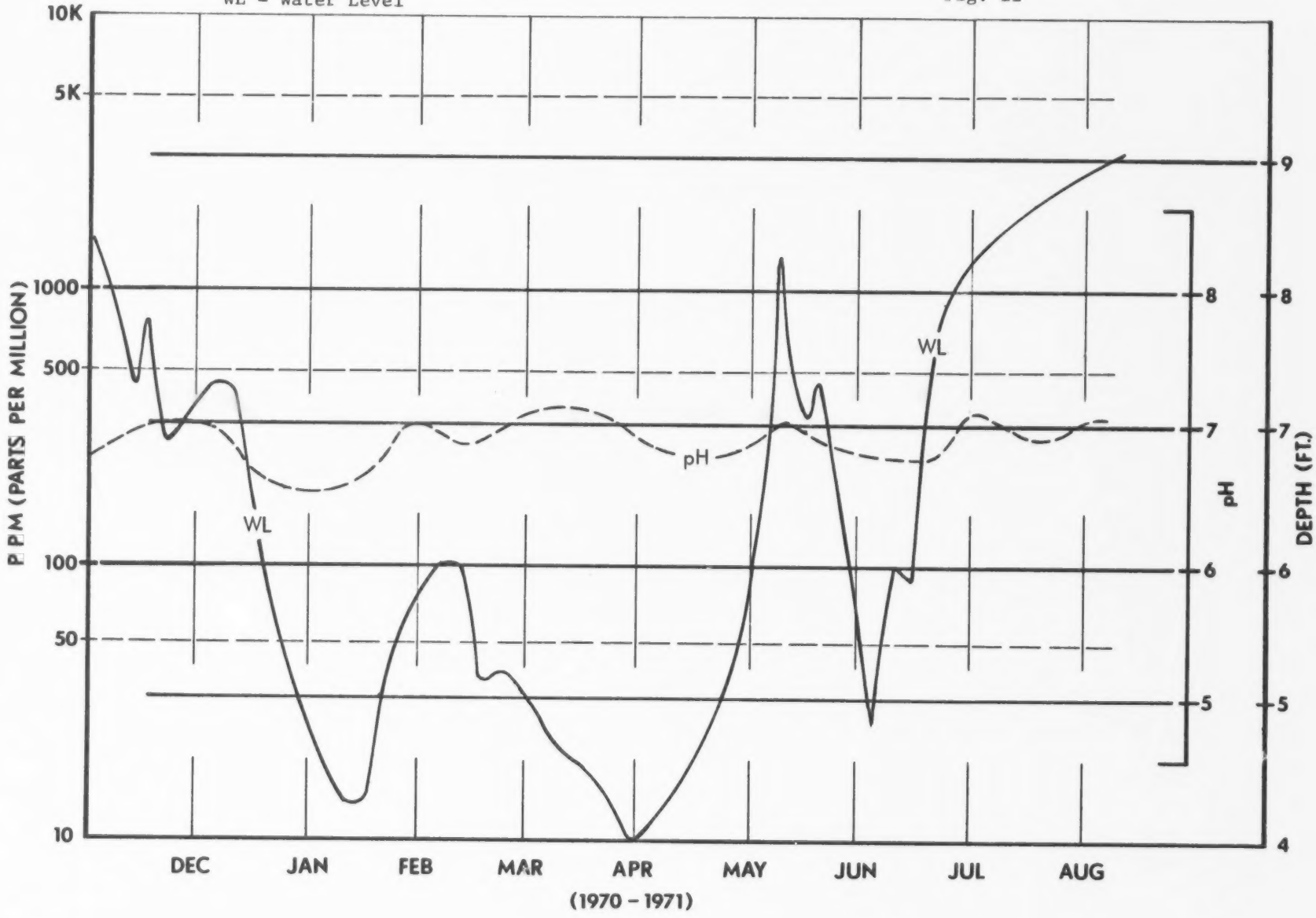


TEST WELL Baseline Well D

MATERIAL TESTED

WL = Water Level

Fig. 11

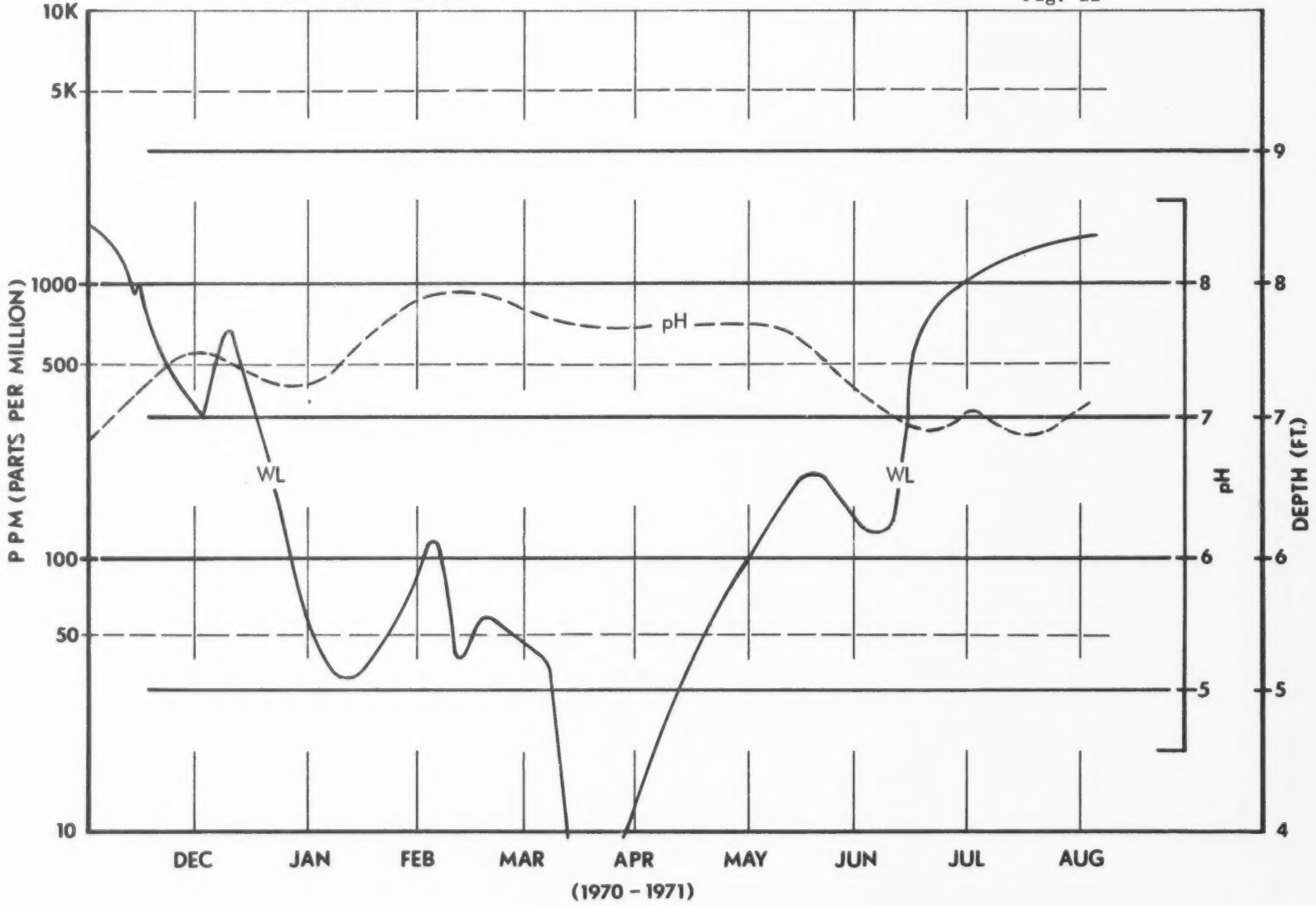


TEST WELL Baseline Well E

MATERIAL TESTED

WL = Water Level

Fig. 12



Rather than flood the cells internally or risk waiting for what would be an abnormal rise in the water table (based on collected data), it was decided to construct an additional pit deep enough to insure ground water penetration. This pit was dug October 2, 1970, to a depth of 10 feet, which was well within the water table (8' 5-1/4" below grade on October 2, 1970). This pit was lined with PVC and equipped with sampling pipes of appropriate lengths (12 feet and eight feet), similar to the original 11 pits. The liquid sealant, Dow Chemical CX 4624, was used as a sealant in order to increase the number of materials being tested (Exhibit L). The cell was then charged, as before, with 14 cubic yards of municipal waste, and covered with a two-foot soil cover.

The choice of a liquid sealant presented problems which were not anticipated. First of all, the liquid sealant permeated the sand-trap sampling area and sealed off the path for any leachate accumulation. This problem was solved by inserting an auger-fitted pipe inside the two-inch sampling pipe and drilling down through the sand trap about two feet deeper than the installed depth of 10 feet six inches. This then allowed the ground water to rise into the sampling pipe.

The second problem, caused by the milky-white color of the sealant, masked the colormetric techniques for chemical analysis. This was solved, for the cell exterior leachate sampling wells, by pumping off (or purging) the liquid in the pipe and flushing with tap water from a garden hose. The interior cell sampling pipe remained a problem, since there was no way to remove this suspended barrier material without defeating its purpose for being there.

Exhibit L

APPLICATION OF DOW CHEMICAL CX 4624

The following list indicates the type and amount of test sealant applied to each of the 12 cells:

Cell 1	Dow Chemical CX 4624 (5 gal.)
Cells 2 and 3	None (used as control cells)
Cell 4	Styrene tar (55 gal.)
Cell 5	Rubber floc waste (450 lb.)
Cell 6	Melted solution of LCA resin (.3 gal./sq. ft.)
Cell 7	Heated asphalt (.15 gal./sq. ft.)
Cell 8	Alcohol C^{20+} waste (.08 gal./sq. ft.)
Cell 9	Bentonite (190 lb.)
Cell 10	Kaiser red mud slurry (55 gal.)
Cell 11	Pond seal (10 gal.)
Cell 12	20-lb. asphalt roofing paper (3 strips)

Cell Monitoring Wells

Landfill cell monitoring wells were established in or near each of the 12 test cells previously described. Two monitoring wells (C and I) were installed, *within* each test cell, as indicated previously. The *C* well penetrated below the bottom of the cell into the supporting local soils, and was designated for contaminant sampling. Well *I* was installed in the interior of the cell so as to reach the half-way depth of the municipal refuse to permit the collection of leachate from within the cell.

Wells were established east of each test cell, and, in some instances, wells were established west of the cells to define an existing condition or suspected condition. These wells were placed less than two feet from the outer edge of each cell, and were designated *E* (east) or *W* (west) wells. The summary chemical data for the baseline wells (Table V) was used as a guide to determine normal and abnormal values for the monitoring wells installed outside the test cells.

A total of 42 exterior and interior wells was installed for the 12 municipal refuse test cells. A total of 340 samples were obtained from these cell monitoring wells, and 2,170 analyses were performed on the 340 samples. Obviously, a tabulation of this mass of data would serve little purpose in this report. Based upon the "norms" established by the baseline well summary data, only an interpretation of the degree of leachate reaching these cell monitoring wells is presented.

There was sufficient literature to indicate that an increase in the chloride, sulfate, nitrate, and phosphate content might be expected, and that these increases would be useful parameters to include as potential leachate indicators. The data collected by the project team did not confirm this precautionary inclusion of these four additional parameters. All of the baseline values were so low that they crowded the accuracy of the methods employed for analysis, and the landfill cell monitoring wells repeated this trend. There was no increase in the values of these parameters, as gross pollution was approached, or achieved, in the cell monitoring wells. One could postulate anionic exchange with the soil.

The following paragraphs summarize the data obtained for each of the 42 monitoring wells, indicated previously in Fig. 4. The Arabic number in the well designation indicates the cell in or near which the well was located. The alphabetic letter, which appears second, indicates the location of the well (E for east; W for west; C for well penetrating below bottom of cell; and I for well reaching half-way of municipal refuse).

Well 1-E

Well 1-E was drilled to a deeper depth than the other test wells (10 feet) and was well below the water table at all times during the study. The cell liner material was Dow Chemical CX 4624, which formed a milky solution within the test cell. This solution remained in suspension for the entire study. Since the sealant

material had a COD of 50,000 mg/l and did reach Well 1-E, chemical parameters of the sealant material, plus the leachate from the municipal refuse, were being measured. The samples from Well 1-E, appeared milky white and odorous one week after the cell was charged with refuse. Within one month, the samples became dark green, with a highly offensive odor. This well was sampled on 21 occasions during an eight-month period. The last month of sampling indicated rapidly improving conditions. A brief summary of pertinent chemical factors is presented in Table VI.

Table VI

EIGHT-MONTH SUMMARY FOR WELL 1-E (mg/l)

Value	pH	BOD	COD	Total Residue
Maximum	7.3	7,600	12,400	8,000
Minimum	5.3	20	5	2,100
Average	6.3	3,240	5,540	5,340

Well 1-W

As an additional check on the direction of the water table movement, and, in an attempt to determine if the PVC film barrier lining within the cell had become ruptured, Well 1-W was installed less than two feet from the west end of Cell 1. The contaminant parameters indicated only mild pollution, since they were only 10 percent above baseline values. The samples were clear, with only a slight odor.

Well 1-C

The sealant material used in Cell 1 penetrated the supporting soil into which 1-C was located. Efforts to ream and flush out this material were unsuccessful, possibly due to sealing of most of the contiguous soil. The pH and BOD values were normal, with

COD values only slightly higher than average baseline values. One can only conclude that leachate entered the water table vertically from the west end cell into Well W.

Well 1-I

Since this interior well was so contaminated by the suspended sealant material, the chemical data was considered to be of little value. It is obvious that the interior of each charged cell is expected to be highly contaminated; the degree is not within the scope of this study.

Well 2-E

Cell 2 was a control plot in which no sealant material was used. During much of the term of this cell, however, it was above the water table, and only rainfall was available to leach through the cell. Four months after Cell 2 was filled with municipal refuse, significant amounts of contamination reached Well 2-E. This contamination continued during the three-month rainy period. Values dropped abruptly between the fourth and eight months, during the dry period. Average values for the wet and dry periods are shown in Table VII.

Table VII

AVERAGE VALUES FOR WET AND DRY PERIODS (mg/l)
(Well 2-E)

Number Samples	pH	BOD	COD	Total Residue
Three-Month Wet Period				
6	6.4	2,090	2,800	3,450
Five-Month Dry Period				
9	6.9	40	75	840

The data in Table VII is considered pertinent because water table and rainfall conditions are similar for the wells for all other cells, and the responses are similar, but to a greater or lesser degree.

Well 2-W

Only two sets of data could be obtained for Well 2-W, due to the low water table. These values were well within the values obtained for the baseline wells.

Well 2-C

All values for Well 2-C were within the baseline study data guidelines.

Well 2-I

An adequate sample volume was available for Well 2-I on only two occasions, six months after the charging of Cell 2. The quantity of rainfall on these occasions permitted leaching from the refuse in the cell. These values are listed, since this was the only true control cell for indicating expected high levels of contaminants.

Table VIII

VALUES OBTAINED FROM TWO SAMPLES
(Well 2-I)

Samples	pH	BOD	COD	Total Residue
1st	5.5	2,640	5,480	4,030
2nd	5.8	1,140	1,850	1,800

Because of the limited rainfall and the fact that only two samples were taken, this data is not indicative.

Well 3-E

Cell 3 was also a control refuse cell, but it was covered with a PVC top in order that the restriction of rainfall percolation

directly into the cell could be evaluated. Monitoring Well 3-E produced normal values for water table characteristics for the first two months, but showed positive pollution for the next three months, during normal rainfall, as the water table rose. Apparently, the direct leaching of rainfall through the cell was successfully restricted, since comparison of values obtained for Well 2-E with values listed below for this well indicates a substantial decrease in values characterizing the leachate.

Three-Month Wet Season, Average Values, mg/l

Number Samples	pH	BOD	COD	Total Residue
7	6.8	490	528	1,140

Restriction of percolation of rainfall through the top of the cell provided a substantial reduction in the offensive odor of the leachate reaching Well 3-E.

Well 3-C

Eight samples were collected from Well 3-C, with all values remaining low during the dry season. The wet weather data for Well 3-C was almost identical to that for the exterior well (3-E) discussed above.

Well 3-I

This interior well remained dry during the entire study, and samples were not available.

Well 4-E

Water samples from this exterior monitoring well had the offensive odor of the styrene tar liner material used in Cell 4. Utilization of this material as a sealant in a large municipal refuse landfill could cause odor problems in streams or shallow wells receiving the water. During the 24 sampling periods,

the BOD for this well was well above baseline values only once; the pH was always normal; the COD was questionably high twice; and the total residues were normal. This material was an effective sealant, but odor was a significant problem.

Well 4-C

Well 4-C was not sampled because of the recurrent lack of water in the well and the presence of the styrene coating in the well shaft, which badly contaminated sampling equipment.

Well 4-I

Well 4-I contained inadequate water for sampling purposes during the entire study.

Well 5-E

Well 5-E was established to monitor leachate from Cell 5, which contained rubber floc as a sealant. The 16 samples obtained from this well were all within baseline values established for the parameters used to identify the presence of leachate.

Well 5-W

Well 5-W was dry, except upon two occasions. The two samples collected at these times indicated that no leachate reached this well.

Well 5-C

Although the two exterior wells discussed above were within baseline values, Well 5-3, which was below the cell sealant material, indicated considerable leachate leakage to the contiguous soil. The values below were averaged, with little spread between values.

Four-Month Wet Season, Average Values, mg/l

Number Samples	pH	BOD	COD	Total Residue
9	7.0	1,400	1,360	2,780

From a chemical and physical standpoint, this sealant material was effective with respect to horizontal movement of the water table, but was ineffective with respect to vertical movement. It must be stressed that, in most instances, vertical leakage shows up ir the E or W wells, but that, in this instance, it did not.

Well 5-I

One sample was collected from Well 5-I during the rainy season as a check on activity occurring in the cell itself. The pH was 5.5; the BOD was 3,000 mg/l; tne COD was 5,500 mg/l; and the total residue was 3,800 mg/l. These values represent maximum activity within the cell due to the high water table.

Well 6-E

Well 6-E monitored the effectiveness of the LCA resin sealant in Cell 6. The average values obtained during 14 sampling periods fell within baseline values, except that the total residue exceeded the baseline values by 200 mg/l. The spread was small between values averaged. This well was considered free of leachate, and the elevated total residues could be characteristic of this particular area.

Average Values, Seven-Month Interval, mg/l

Number Samples	pH	BOD	COD	Total Residue
14	7.1	21	41	800

Well 6-W

Because of the low water table, only two samples were collected from this well. All parameters were within the values established for the baseline wells.

Well 6-C

During the first five months, Well 6-C received no leachate. During the relatively dry month of June 1971, one sample indicated considerable leachate, with a BOD of 900 mg/l and a COD of 1,850 mg/l. The sample after this polluted sample indicated that the well was almost normal. This seemed to be a temporary break in the sealant.

Well 7-E

Well 7-E contained water during the entire study. Since the well was installed just prior to the wet season of January, February, and March, 1971, the earlier samples were the only samples containing moderate pollution. Since asphalt is known to be a good sealant, mechanical difficulties would be most suspect.

Table IX

AVERAGE VALUES FOR WET AND DRY PERIODS (mg/l)
(Well 7-E)

Number Samples	pH	BOD	COD	Total Residue
Three-Month Wet Period				
5	7.0	480	340	1,070
Five-Month Dry Period				
9	7.3	15	45	700

Well 7-E received moderate concentrations of leachate during heavy rainfall.

Well 7-W

Seven samples collected from Well 7-W during a four-month period were all within baseline values.

Well 7-C

Five samples collected from Well 7-C below the asphalt sealant indicated a good seal, and there was no evidence of leachate. This

strongly indicates that the leachate erupted through the east wall of the cell (which was lined with a PVC liner), since the west well showed no evidence of contamination.

Well 8-E and Well 8-C

Cell 8, lined with Alcohol C^{20+}, was again a low-rainfall/low-contamination situation. Exterior monitoring Well 8-E and 8-C Well, below the sealant material, were sampled on 12 and five occasions, respectively. During normal rainfall and a high water table, the BOD and COD were higher than baseline data by a factor of seven to 10. The total residue was higher by a factor of two. During the five dry-weather months (April to August), samples indicated that no measurable leachate was reaching either of these wells. Because of the differences noted during low-water/high-water table conditions, it seems mechanical factors may have been the cause.

Well 9-E

Well 9-E was installed to monitor leachate from the east wall of Cell 9, which was sealed with bentonite on the bottom surface. This well had moderate pollution during the rainy season, comparable in magnitude to that for Well 8-E. The samples collected during the five-month period of low water tables were all comparable to baseline values and indicated that no leachate entered this well.

Well 9-W

Well 9-W presented acceptable water quality over a five-month period, including the rainy season. Values for all parameters were not above those established by the baseline well monitoring data.

Well 9-C

The data obtained from Well 9-C confirmed the usefulness of bentonite as a sealant for ponds, impoundments, and other areas. A summary of average values is listed below. There were no significant peak values, and all samples were collected during the rainy season.

Average Values, Four-Month Interval, mg/l

Number Samples	pH	BOD	COD	Total Residue
6	7.3	3.	7.	670

In summary, leachate was detected near the east well of Cell 9, but the west well and control well beneath the bentonite sealant did not receive detectable leachate.

Well 10-E

Well 10-E was designed to measure escape of leachate from Cell 10, in which "red mud" was used as a sealant. The well was installed in December 1970, and was first sampled in January 1971. The two samples collected in January indicated moderate, but positive, presence of leachate. An additional 12 samples were obtained during the period February to August, and these indicated no evidence that leachate reached this well. A physical factor, such as compaction, may have permitted the initial release of leachate. The "red mud" was poured as a slurry into the cell.

Well 10-W

Well 10-W was sampled only during the dry season. There was no evidence of contamination.

Well 10-C

Well 10-C was sampled only during the wet season. Because of the low water table, the well was dry during the study. Since only three samples were obtained, all values are listed in Table X.

Table X

VALUES FOR THREE SAMPLE DATES
(Well 10-C)

Date	pH	BOD	COD	Total Residue	Nonfilterable Residue
2-12-71	5.3	5,600	3,800	5,430	4,850
2-18-71	5.3	4,800	835	4,650	4,430
3-29-71	8.3	--	330	--	1,300

The data in Table X indicates gross pollution, compared to the values obtained for the baseline wells. This data is inconclusive because of the lack of adequate samples to define the conditions. During the one period of high water table, the sealant material, or the seal around the well shaft, was inadequate.

Well 11-E

Six samples were obtained from Well 11-E during the wet season (January through March 1971). These samples indicated moderate leachate contamination of this well, which monitored the pondseal sealant for Cell 11. This well contained water during the entire period of the study. Eight samples collected during the dry period (April to August) indicated no contamination by leachate.

Well 11-W

There was no evidence of leachate contamination from Well 11-W.

Well 11-C

All results for Well 11-C, with one exception, indicated there was no pollution from leachate. This well was sampled on 10 occasions. Nine samples were well within baseline values, but the last sample indicated a tenfold increase in BOD, and a threefold increase in total residue. This sample was obtained in the middle of the dry season.

Well 11-I

The data obtained from various samplings of this well (within Cell Cell 11) is listed merely as a possible item of interest to the reader.

pH	BOD	COD	Total Residue	Nonfilterable (mg/l) Residue
5.5	7,600	5,700	7,700	--
5.2	6,600	13,600	7,800	--
5.4	6,500	9,400	6,000	3,000

Well 12-E

This well monitored Cell 12, in which asphalt roofing felt was used as the sealant for the bottom of the cell. Fifteen (15) samples were collected from this well, which was east of the test cell. The well was first sampled in January 1971. Eleven (11) samples obtained from January through June were moderately polluted. July and August samples were within baseline values. Since Cell 12 also contaminated baseline Well A, and since the roofing felt is generally considered impervious to moisture, mechanical failure is suspected.

Well 12-W

The first sample from Well 12-W was collected in April 1971, and indicated moderate contamination by leachate. A second sample in May indicated diminishing concentrations of leachate. Five additional samples obtained during June to August were within the baseline data criteria.

Well 12-C

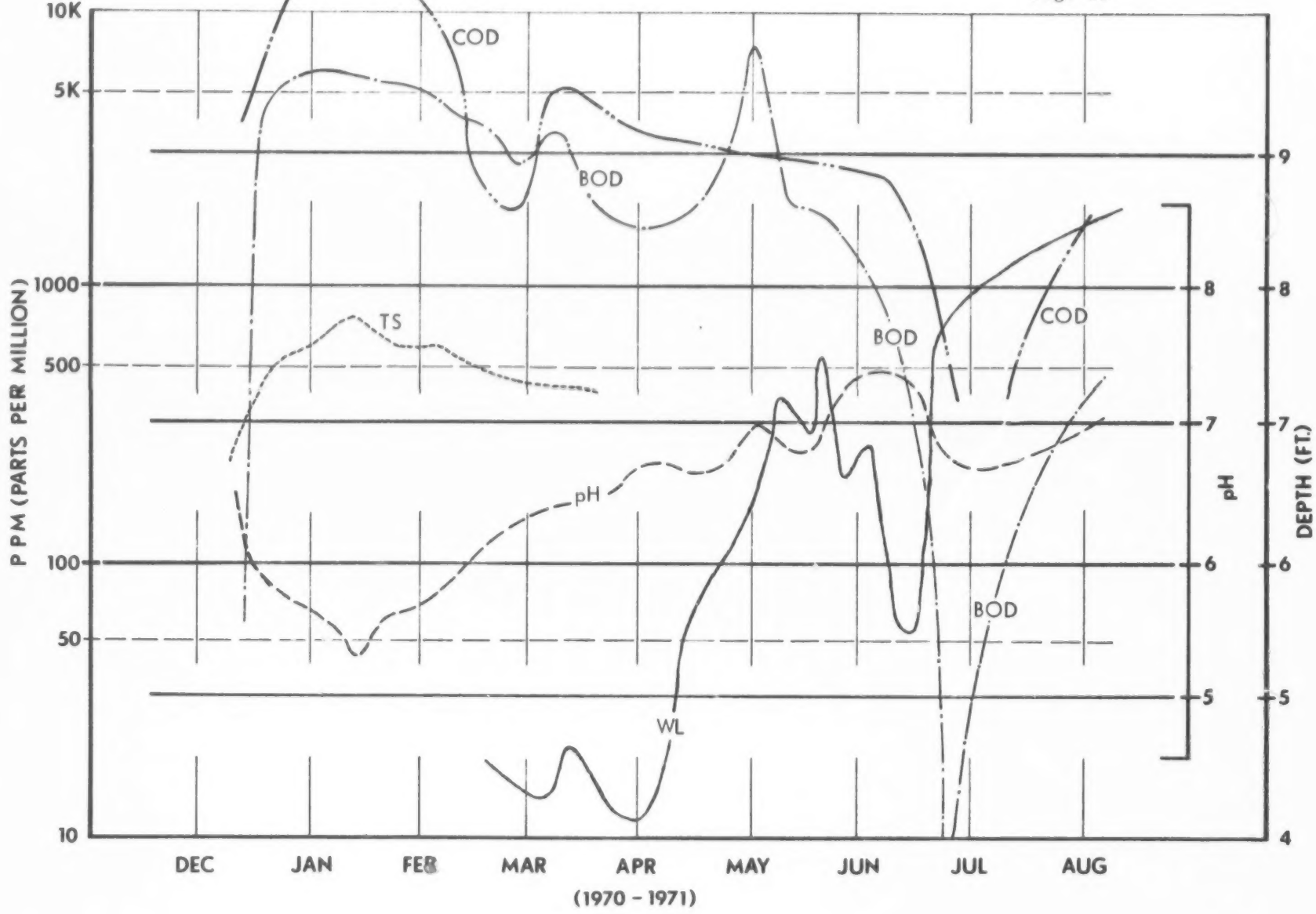
Well 12-C contained moderate amounts of leachate from December 1971, through June 1972.

Figures 13 through 37 are plots of data for those wells for which adequate data was obtained.

TEST WELL 1-E

MATERIAL TESTED Dow Chemical Company CX4624

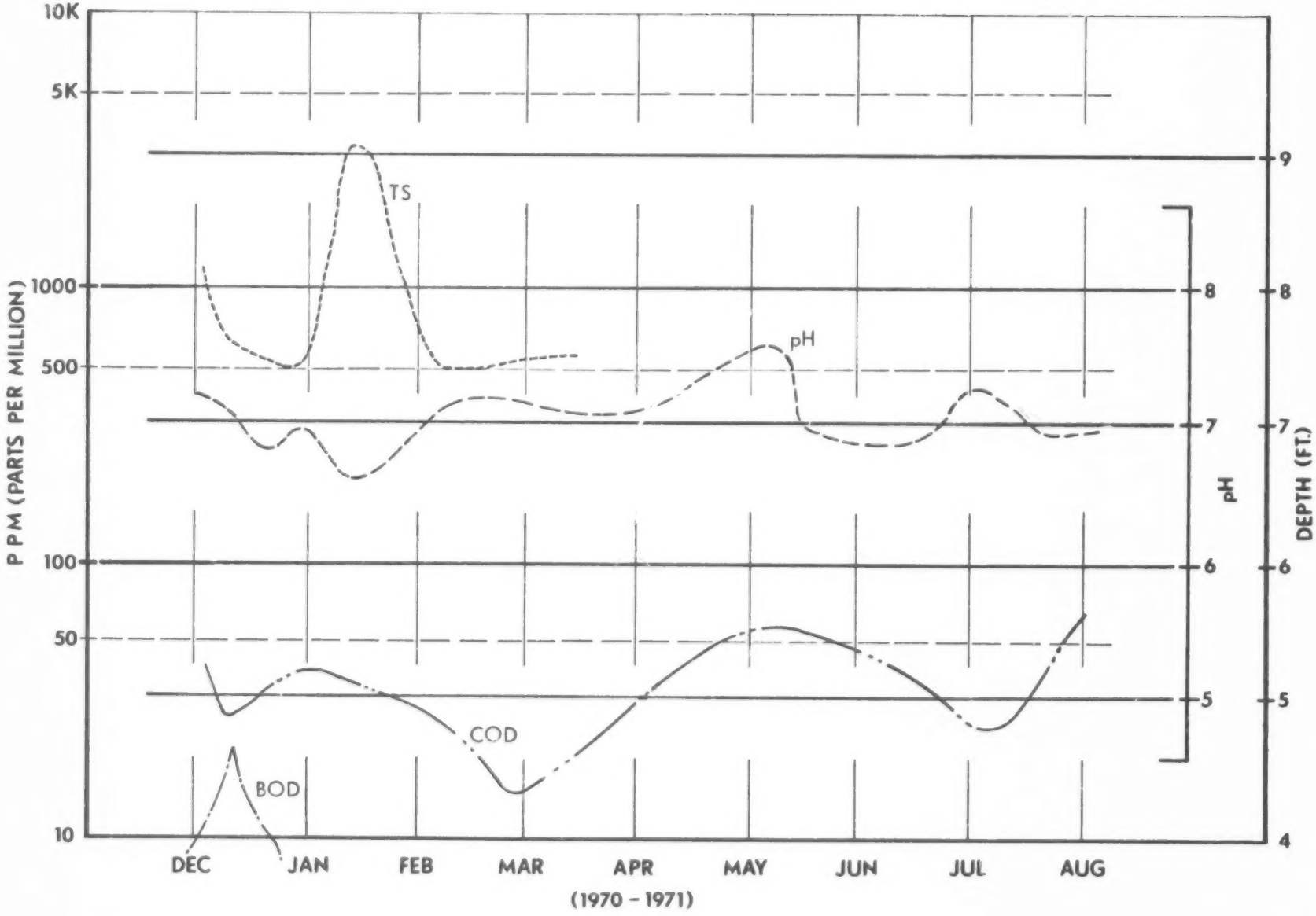
Fig. 13



TEST WELL 1-C

MATERIAL TESTED Dow Chemical Company CX4624

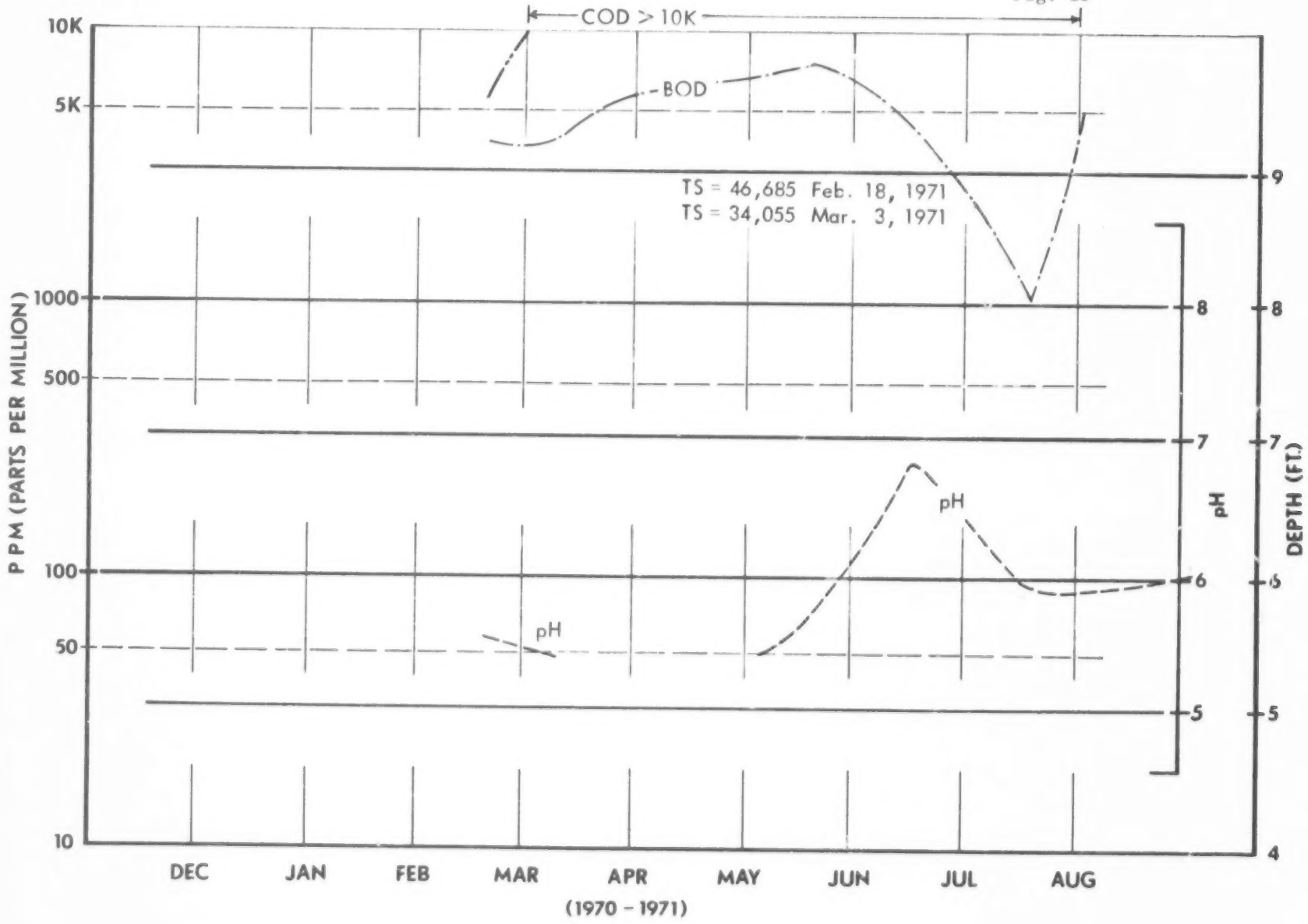
Fig. 14



TEST WELL 1-I

MATERIAL TESTED Dow Chemical Company CX4624

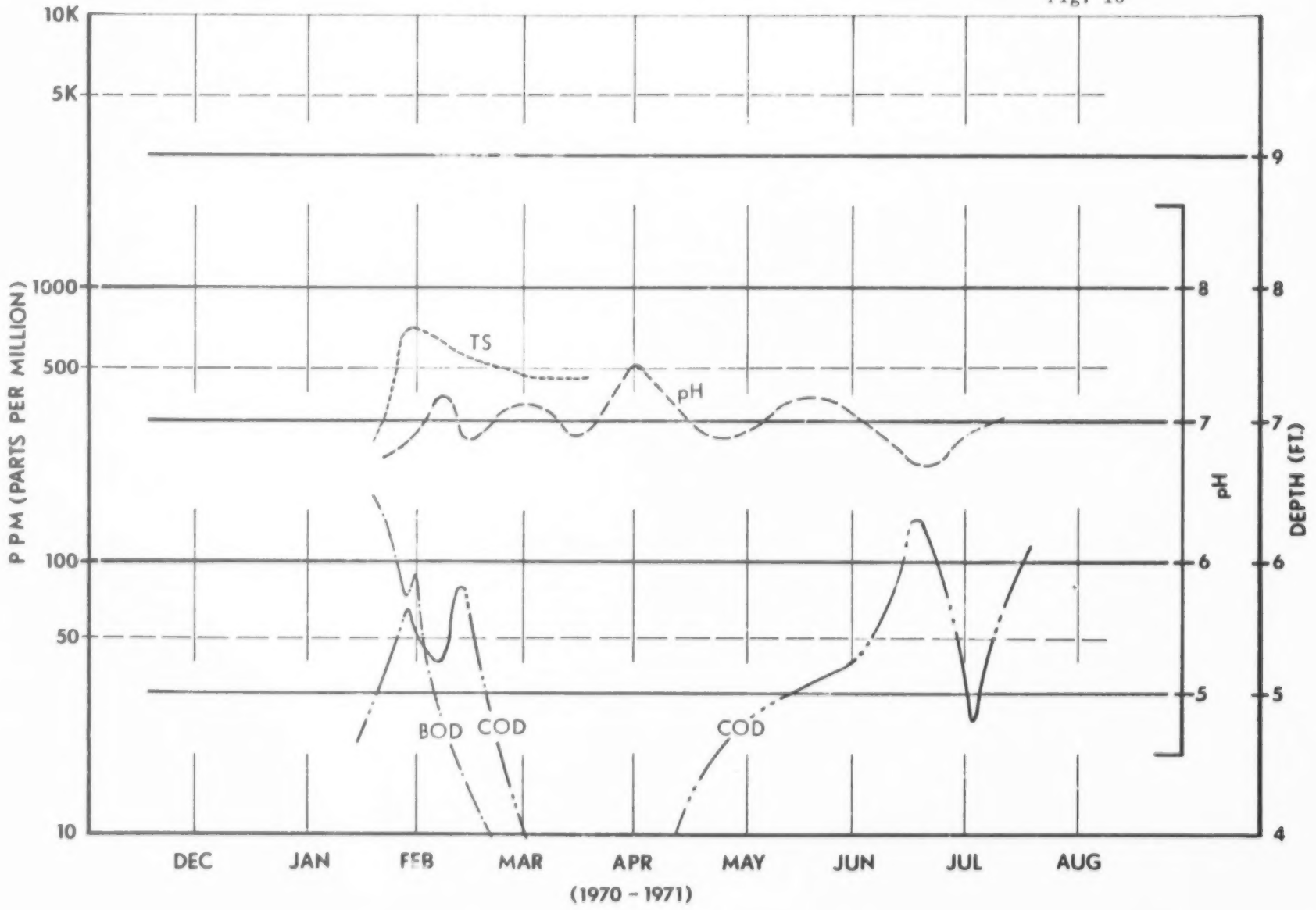
Fig. 15



TEST WELL 1-W

MATERIAL TESTED Dow Chemical Company CX4624

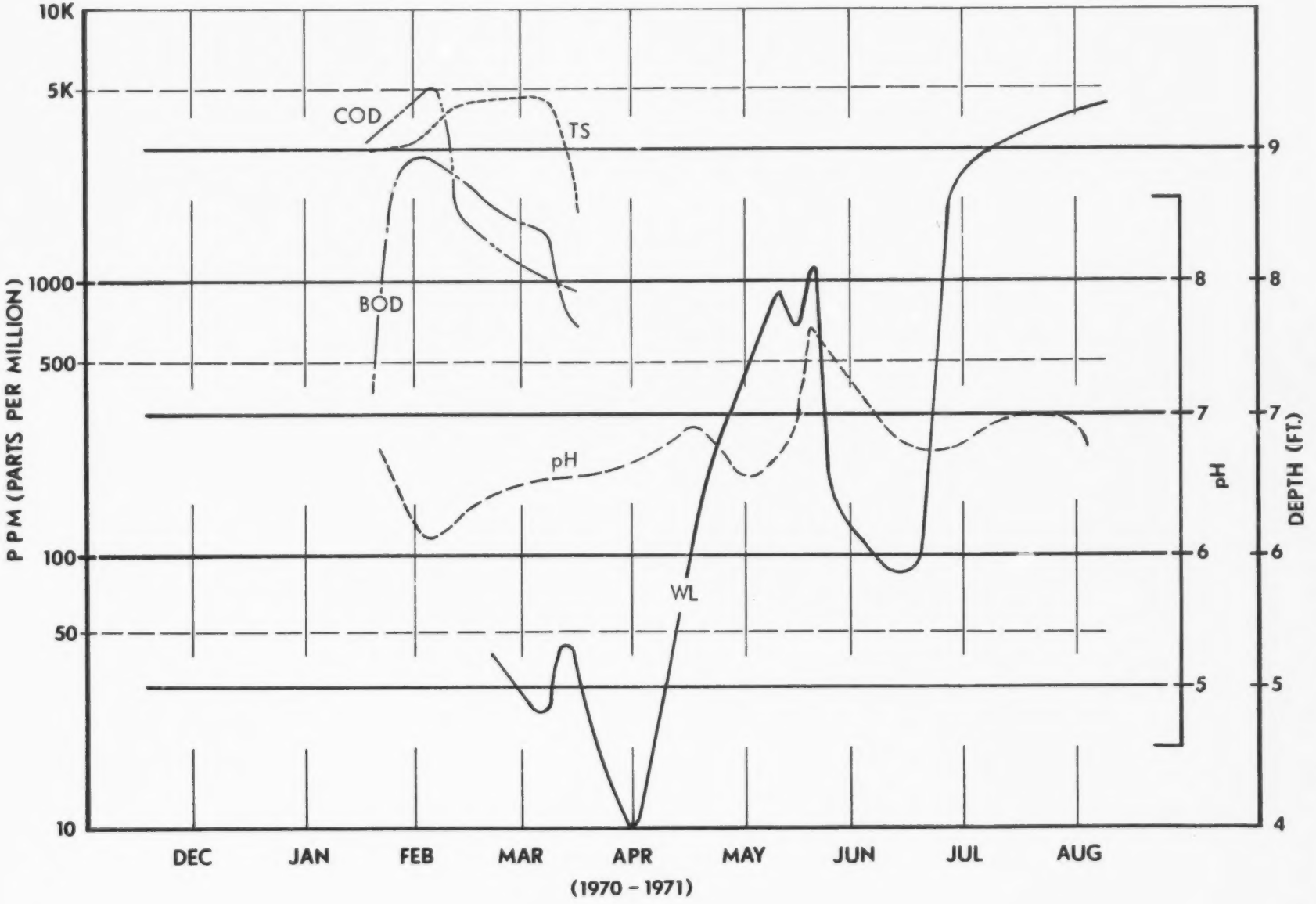
Fig. 16



TEST WELL 2-E

MATERIAL TESTED None (Control Cell)

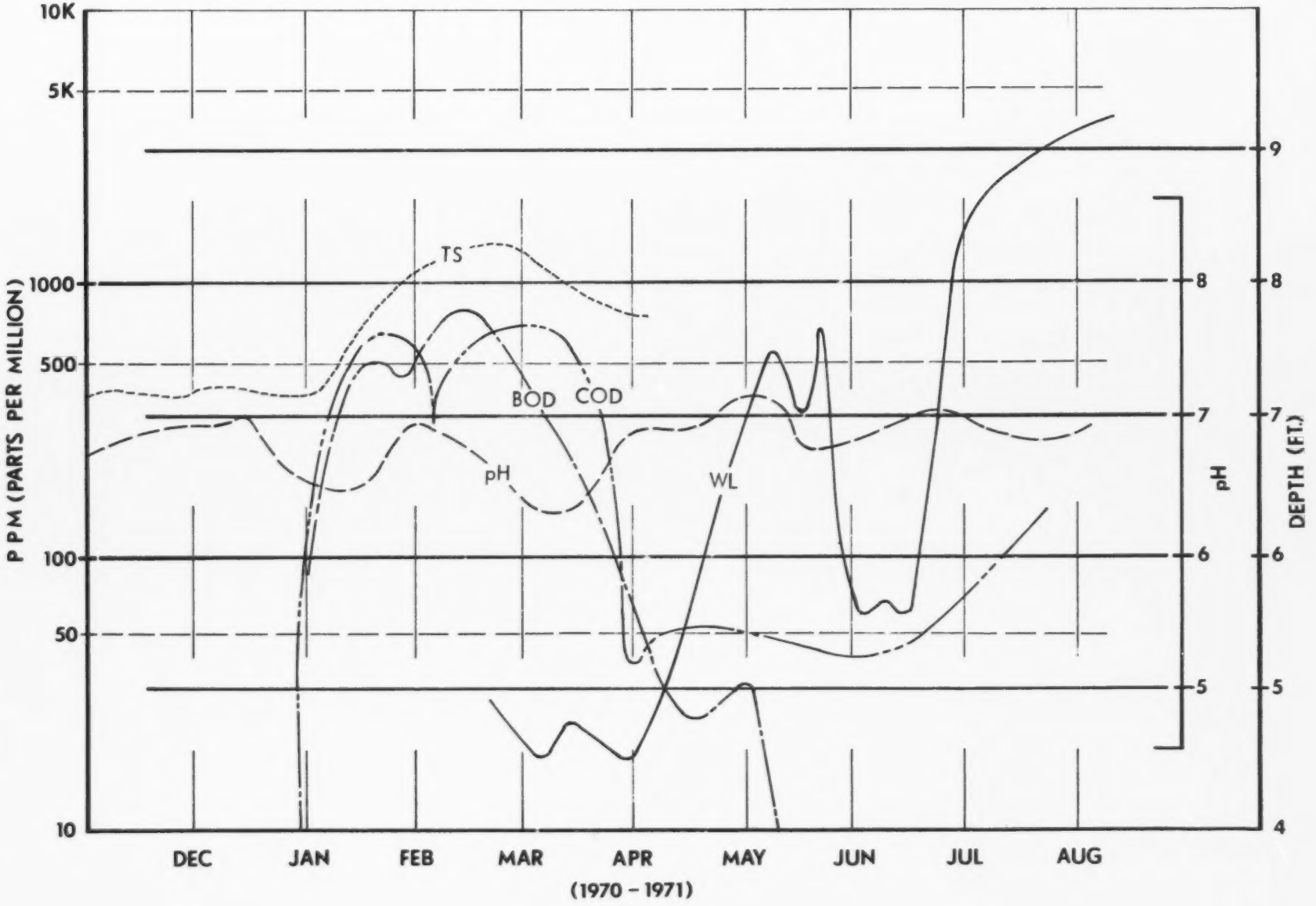
Fig. 17



TEST WELL 3-E

MATERIAL TESTED None (Control Cell) PVC Cover

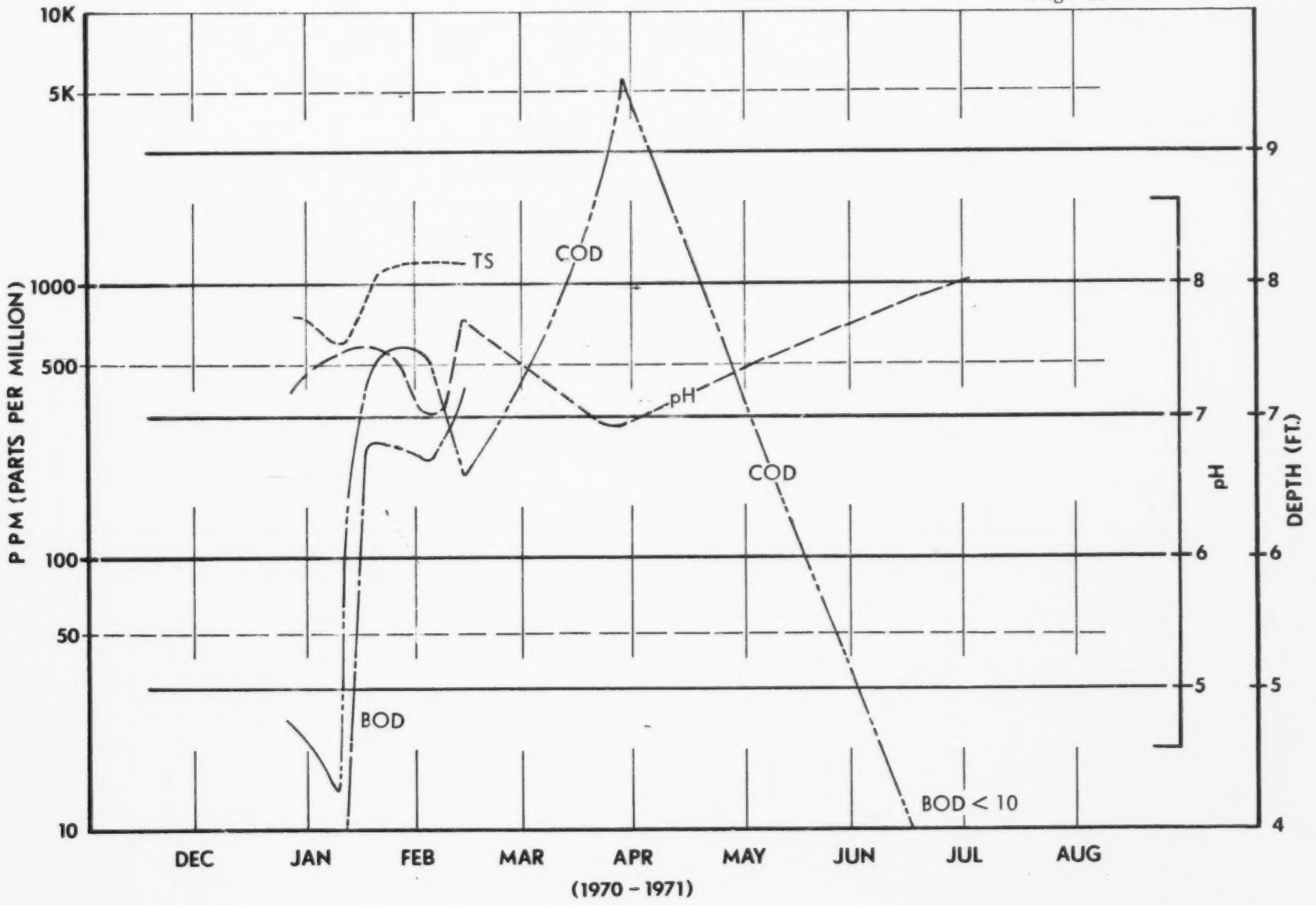
Fig. 18



TEST WELL 3-C

MATERIAL TESTED None (Control Cell) PVC Cover

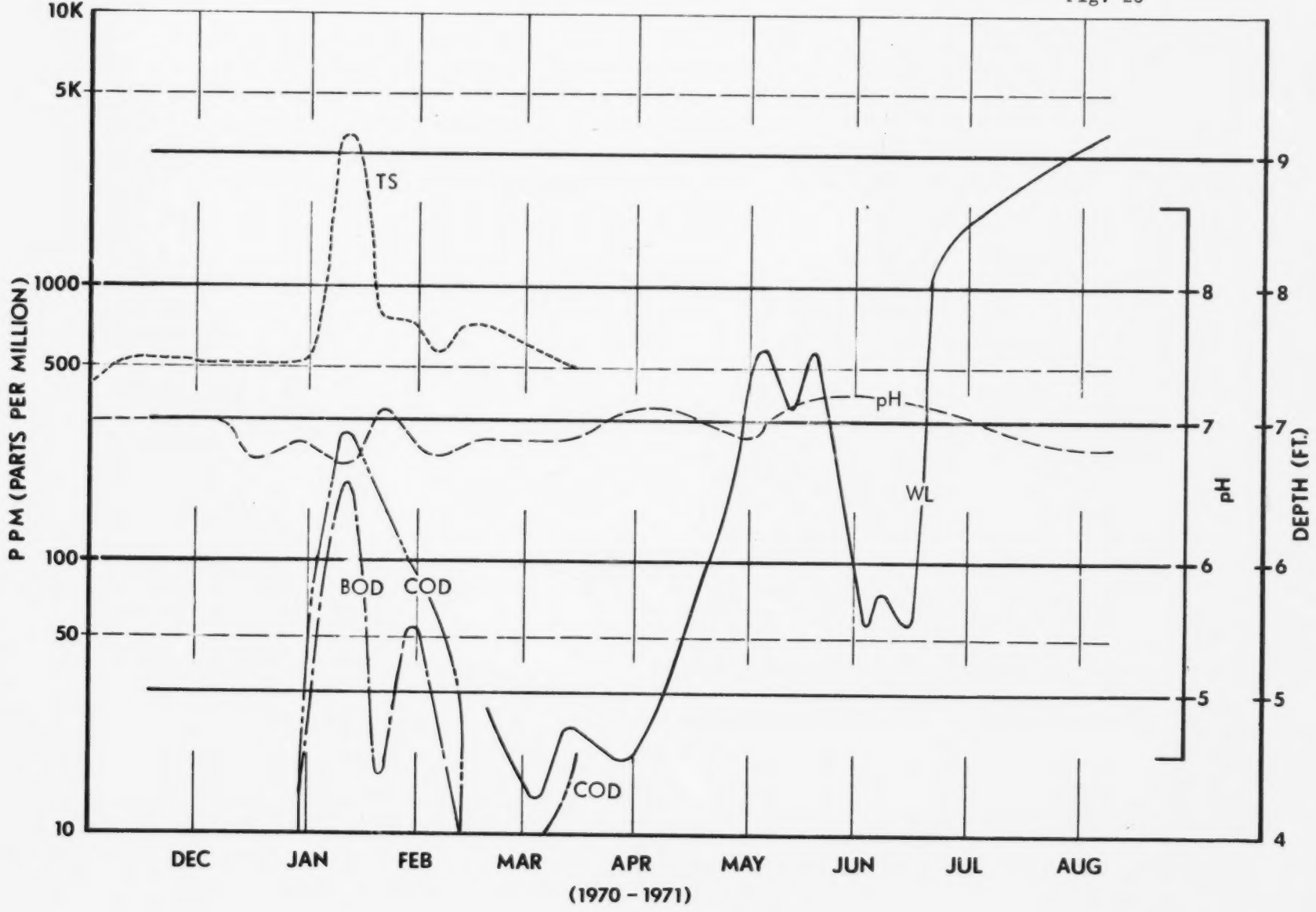
Fig. 19



TEST WELL 4-E

MATERIAL TESTED Styrene Tar

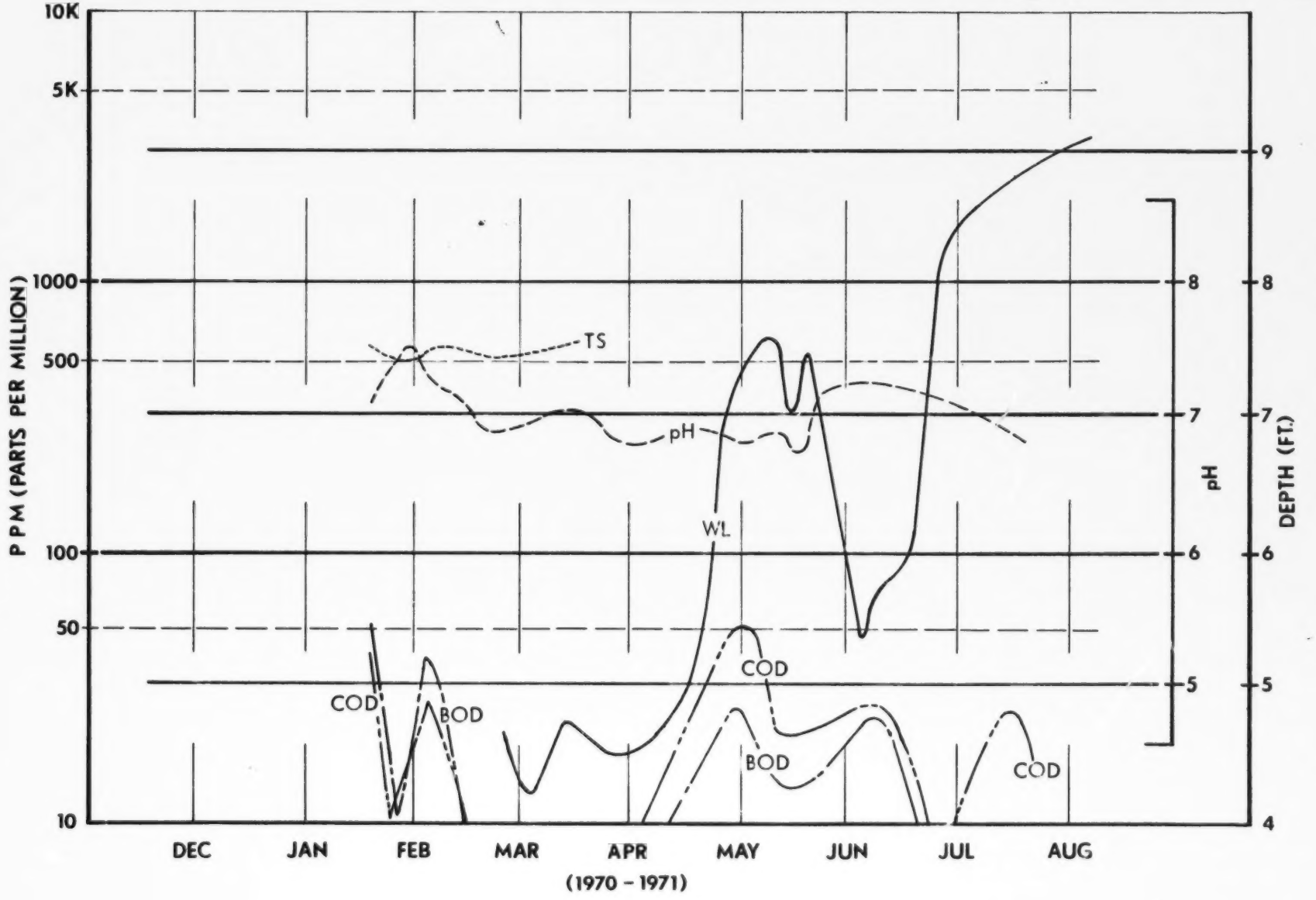
Fig. 20



TEST WELL 5-E

MATERIAL TESTED Rubber Floc Waste

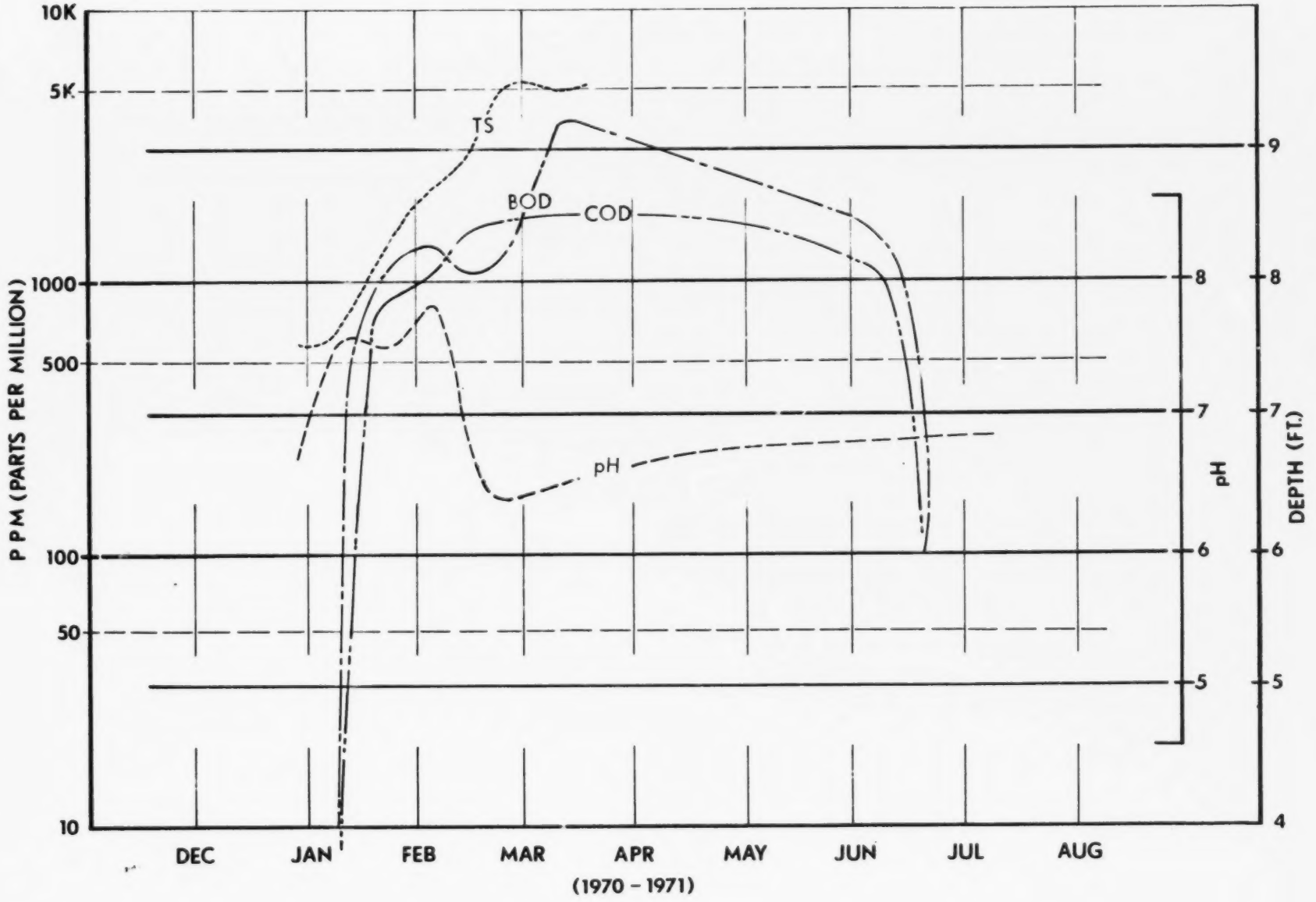
Fig. 21



TEST WELL 5-C

MATERIAL TESTED Rubber Floc Waste

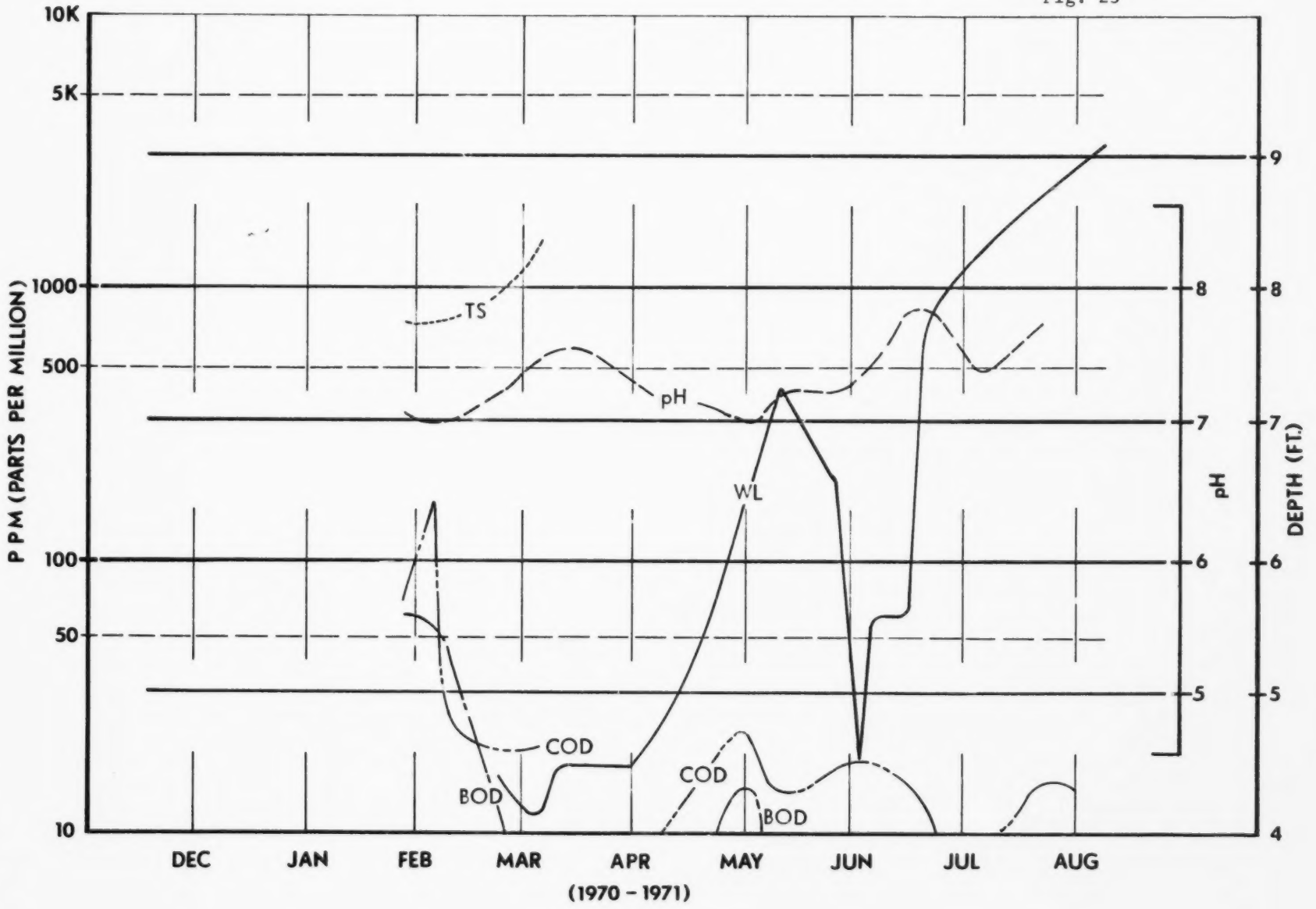
Fig. 22



TEST WELL 6-E

MATERIAL TESTED LC/ Resin

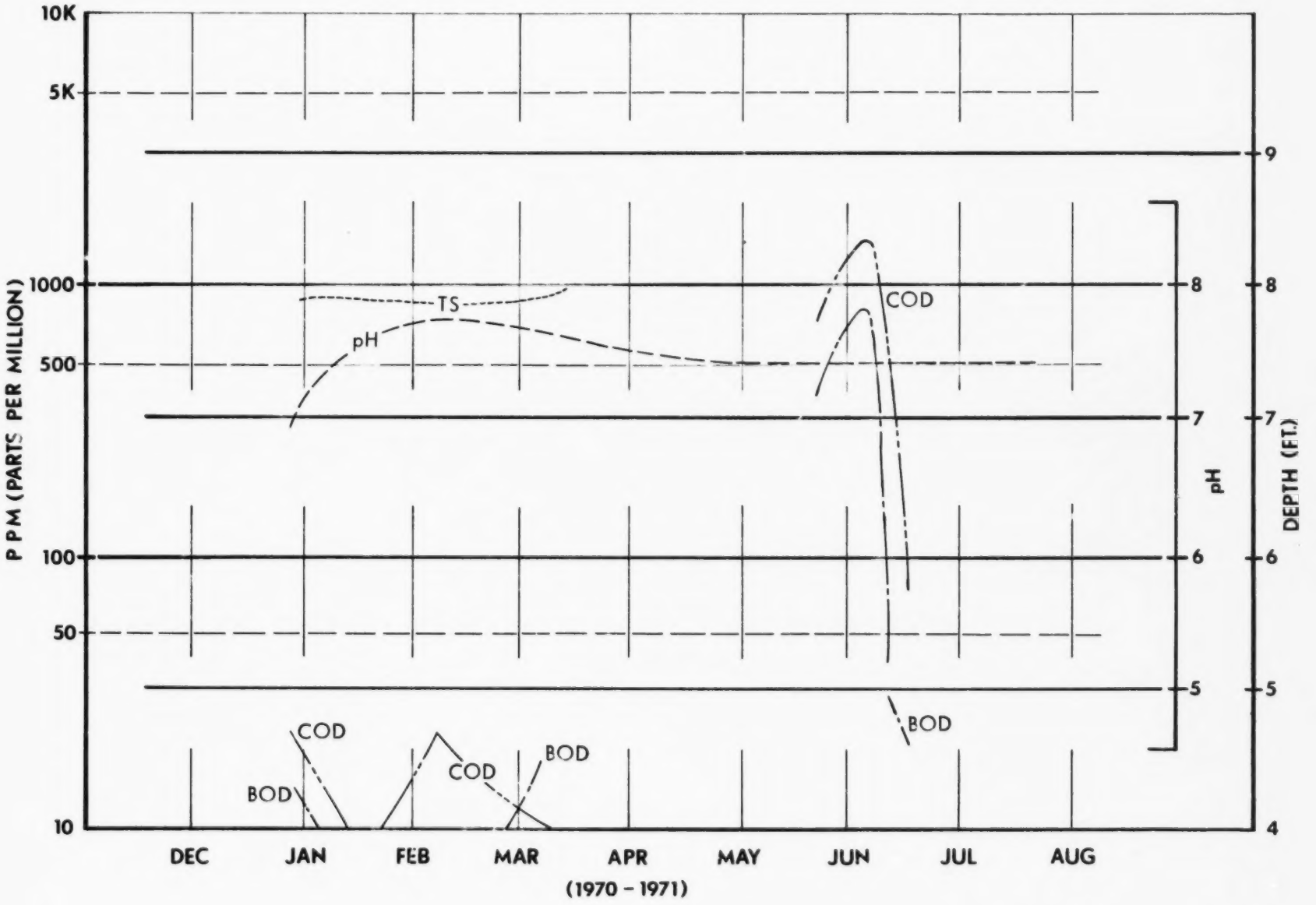
Fig. 23



TEST WELL 6-C

MATERIAL TESTED LCA Resin

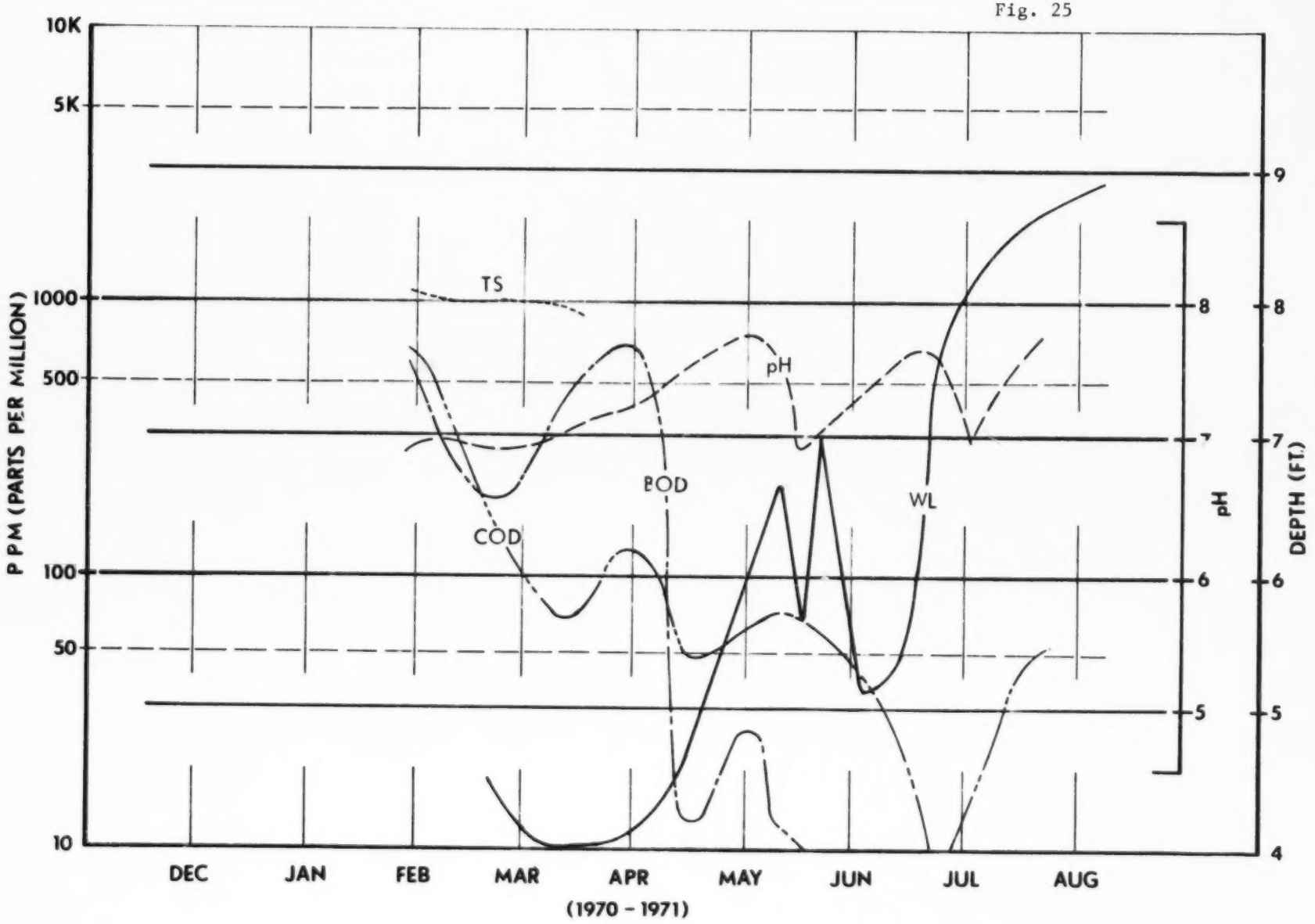
Fig. 24



TEST WELL 7-E

MATERIAL TESTED Asphalt

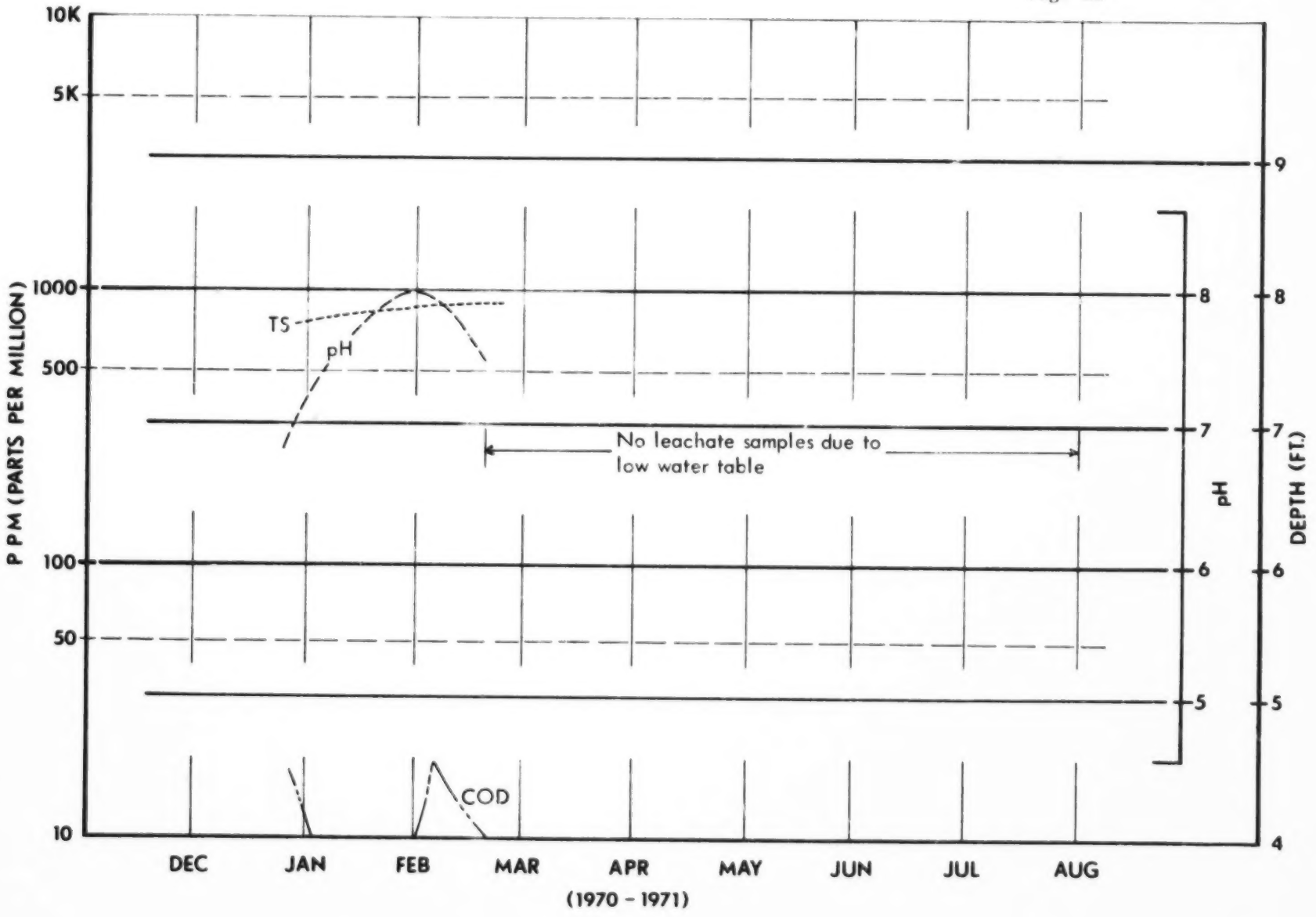
Fig. 25



TEST WELL 7-C

MATERIAL TESTED Asphalt

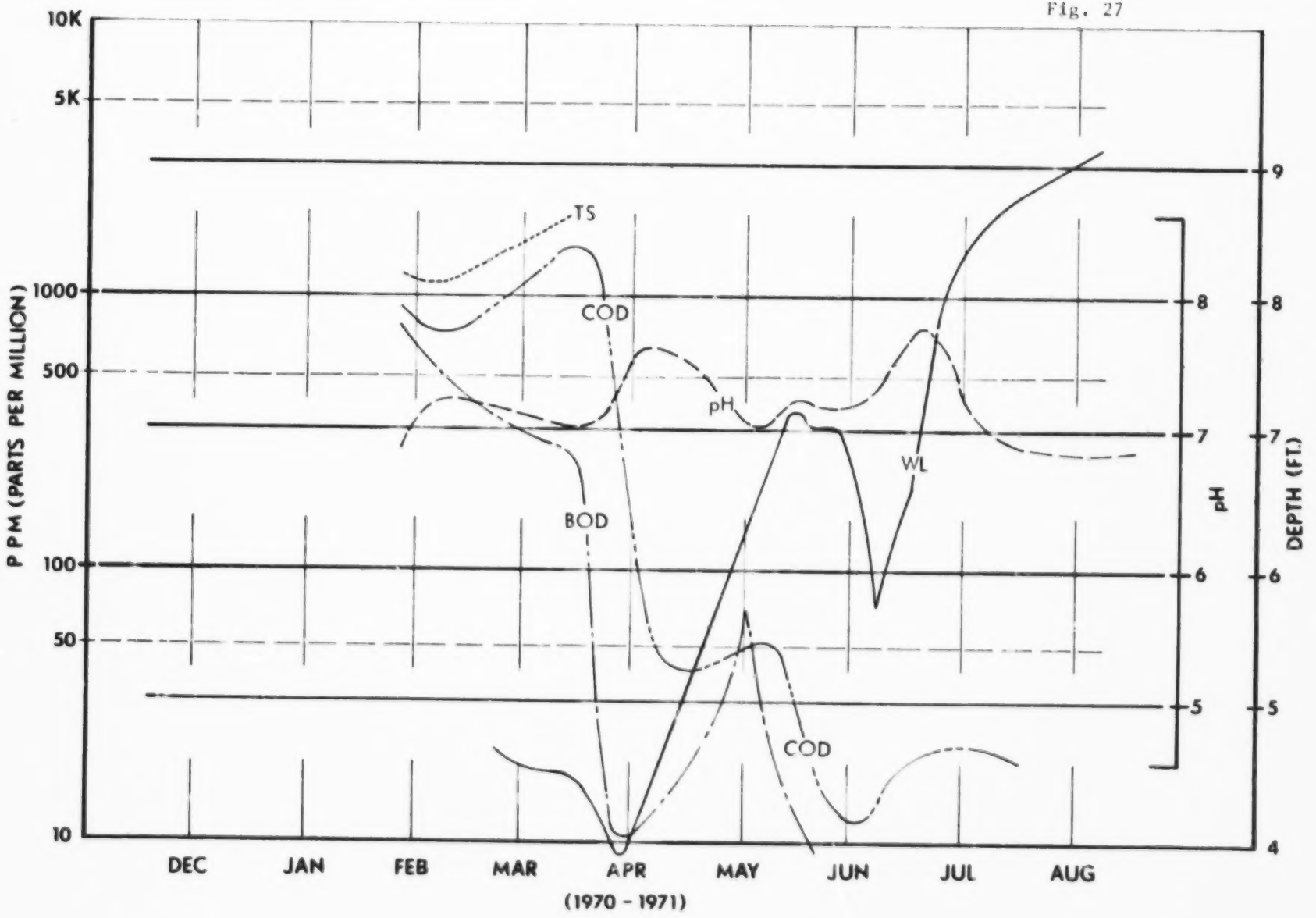
Fig. 26



TEST WELL 8-E

MATERIAL TESTED Alcohol C^{20+}

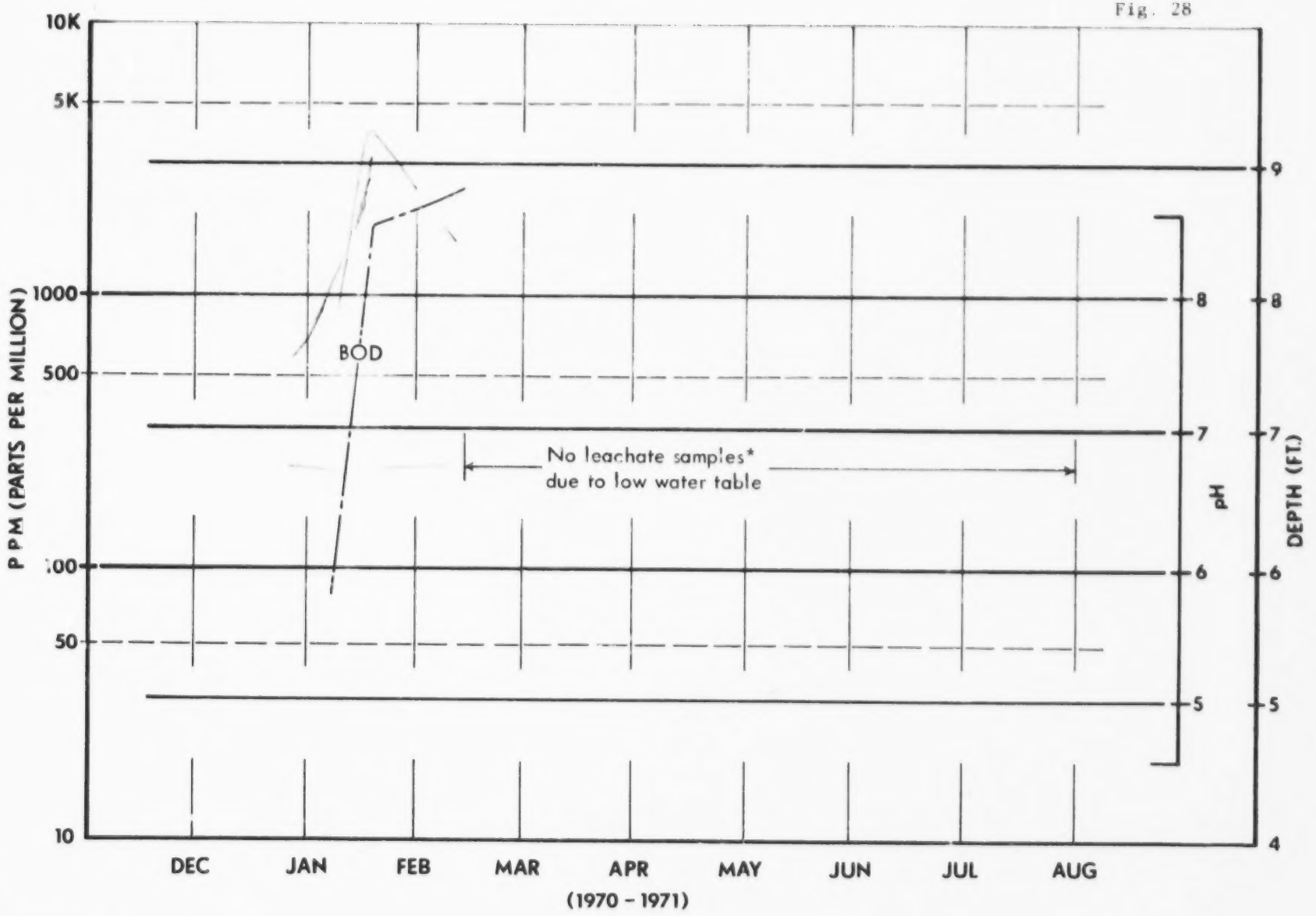
Fig. 27



TEST WELL 8-C

MATERIAL TESTED Alcohol C^{20+}

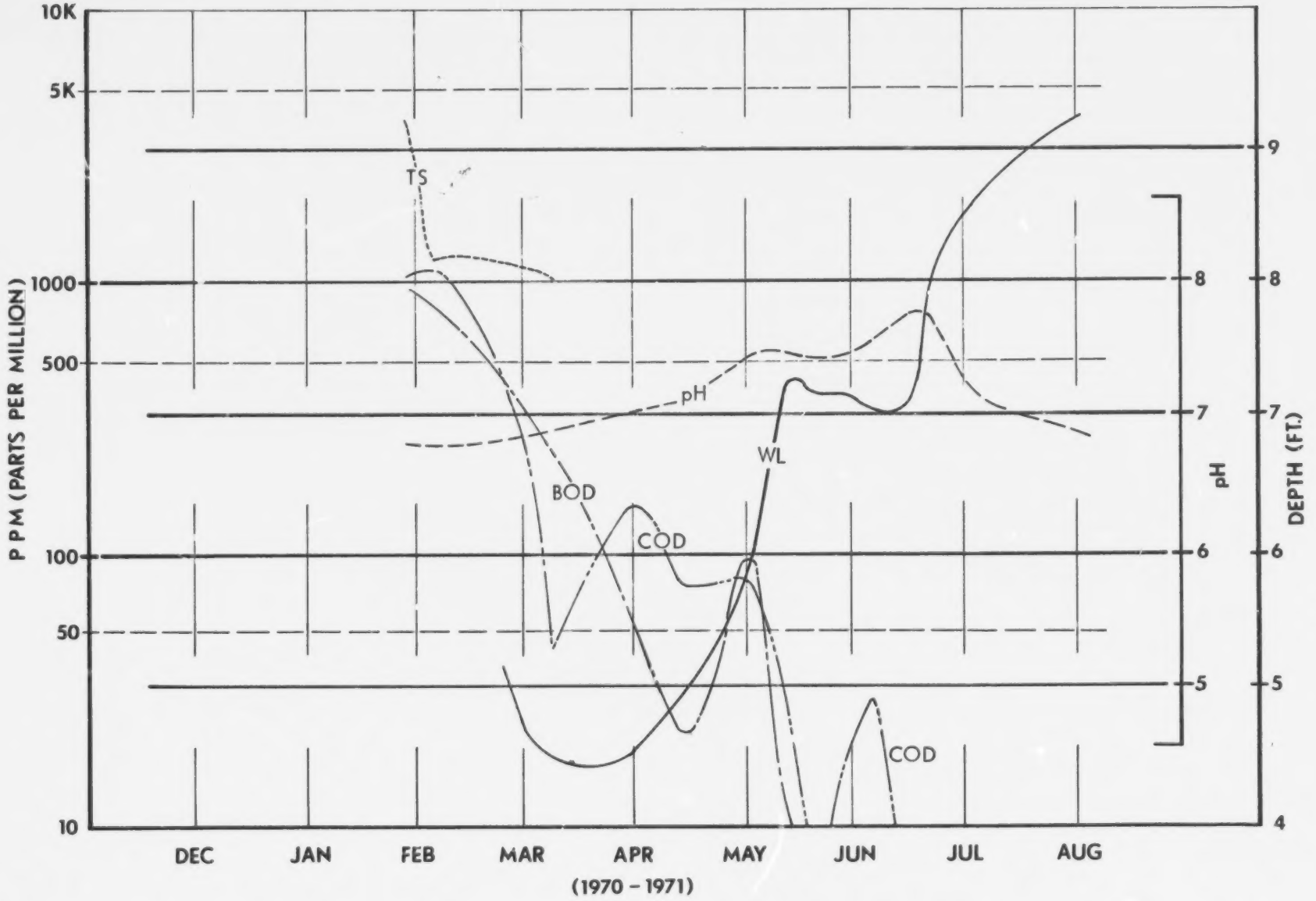
Fig. 28



TEST WELL 9-E

MATERIAL TESTED Bentonite

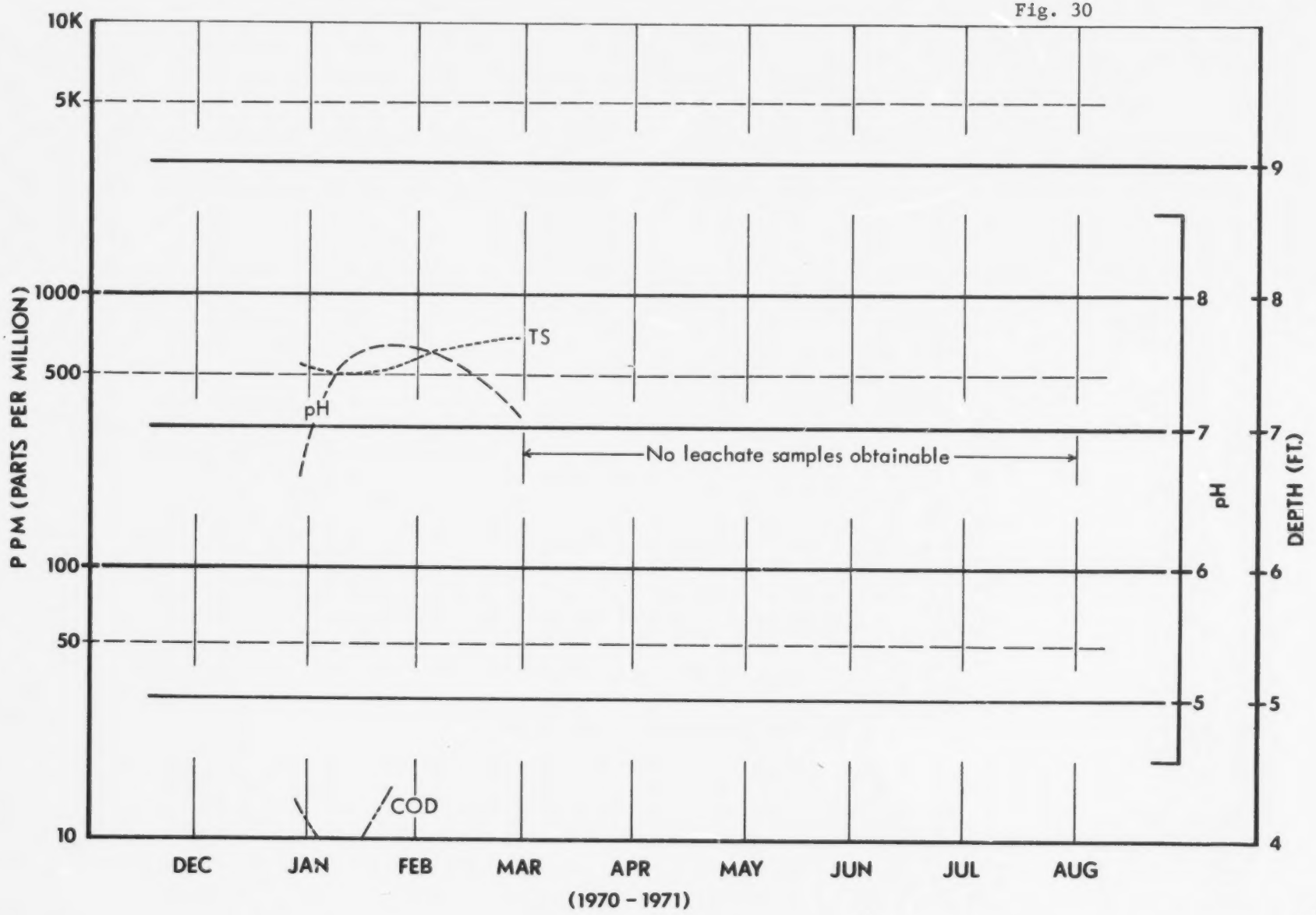
Fig. 29



TEST WELL 9-C

MATERIAL TESTED Bentonite

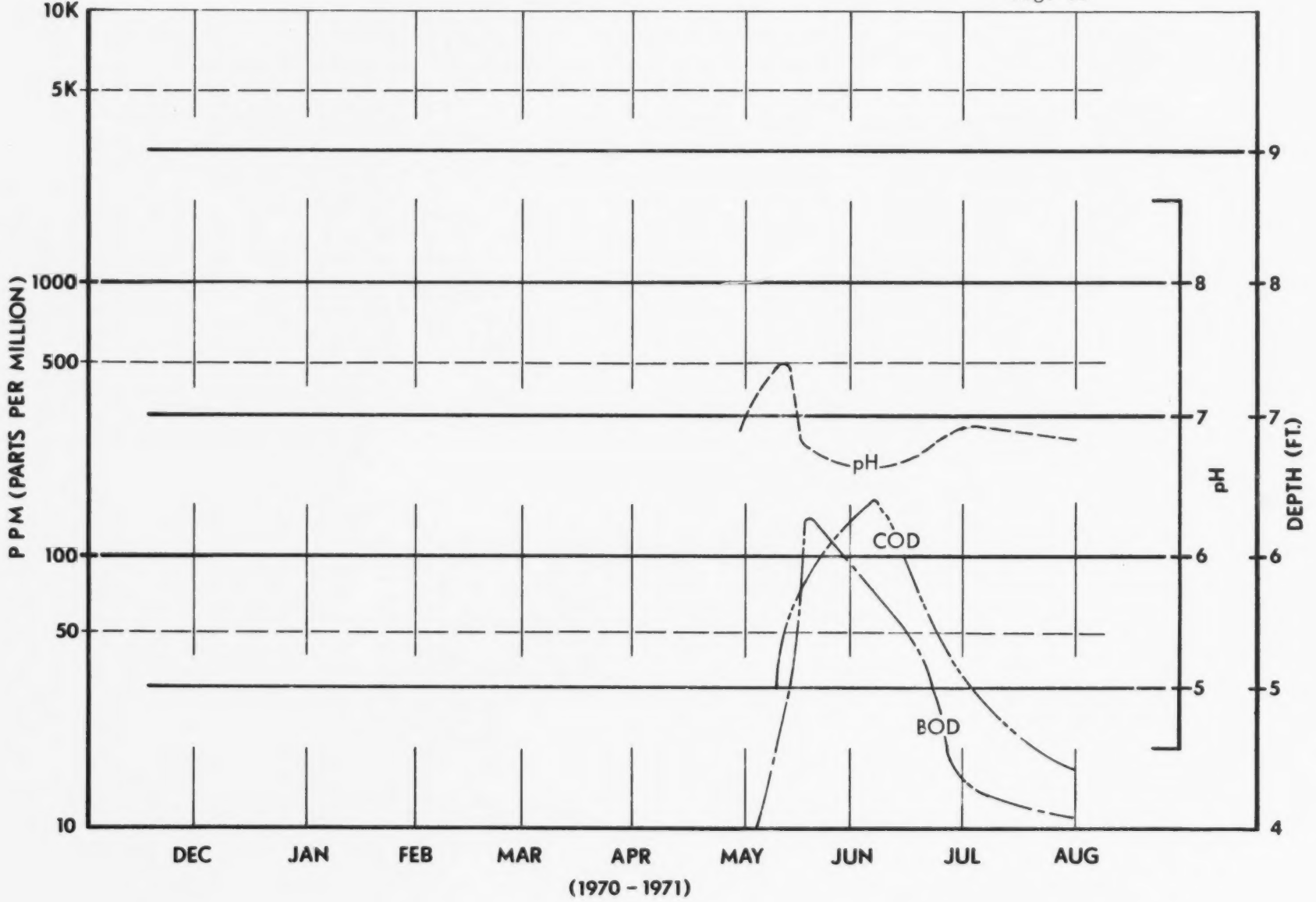
Fig. 30



TEST WELL 9-W

MATERIAL TESTED Bentonite

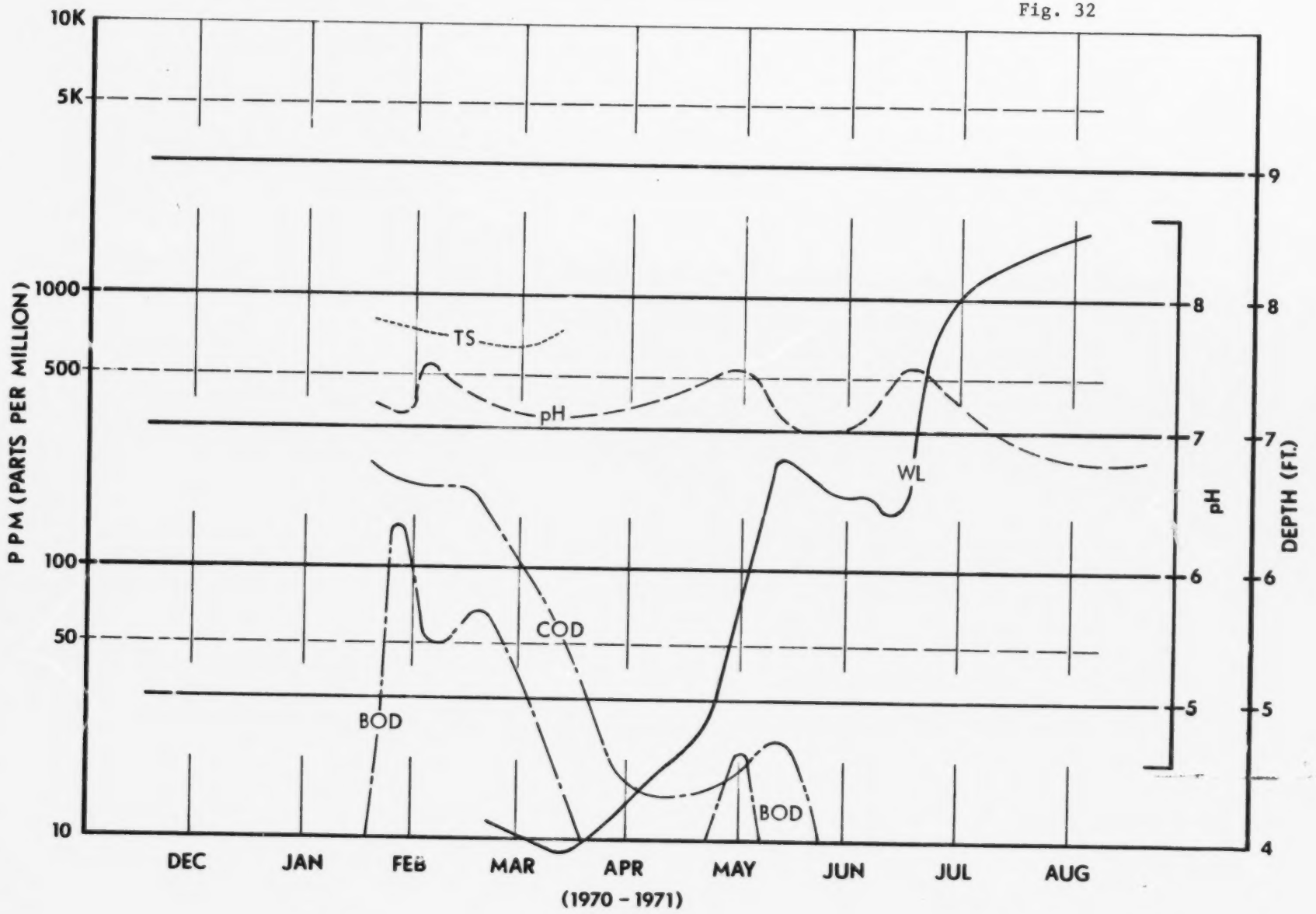
Fig. 31



TEST WELL 10-E

MATERIAL TESTED Kaiser Red Mud Slurry

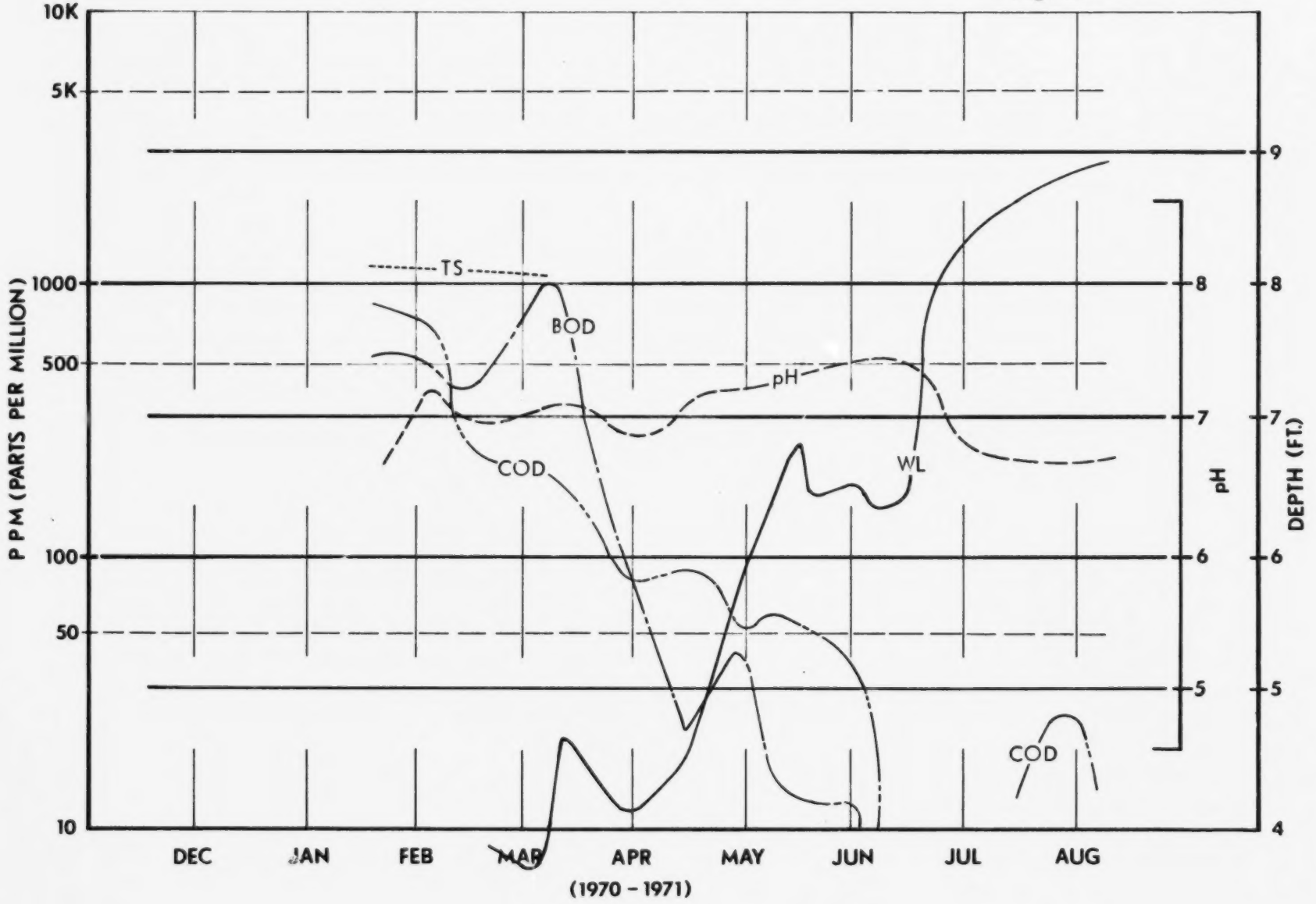
Fig. 32



TEST WELL 11-E

MATERIAL TESTED Pond-Seal

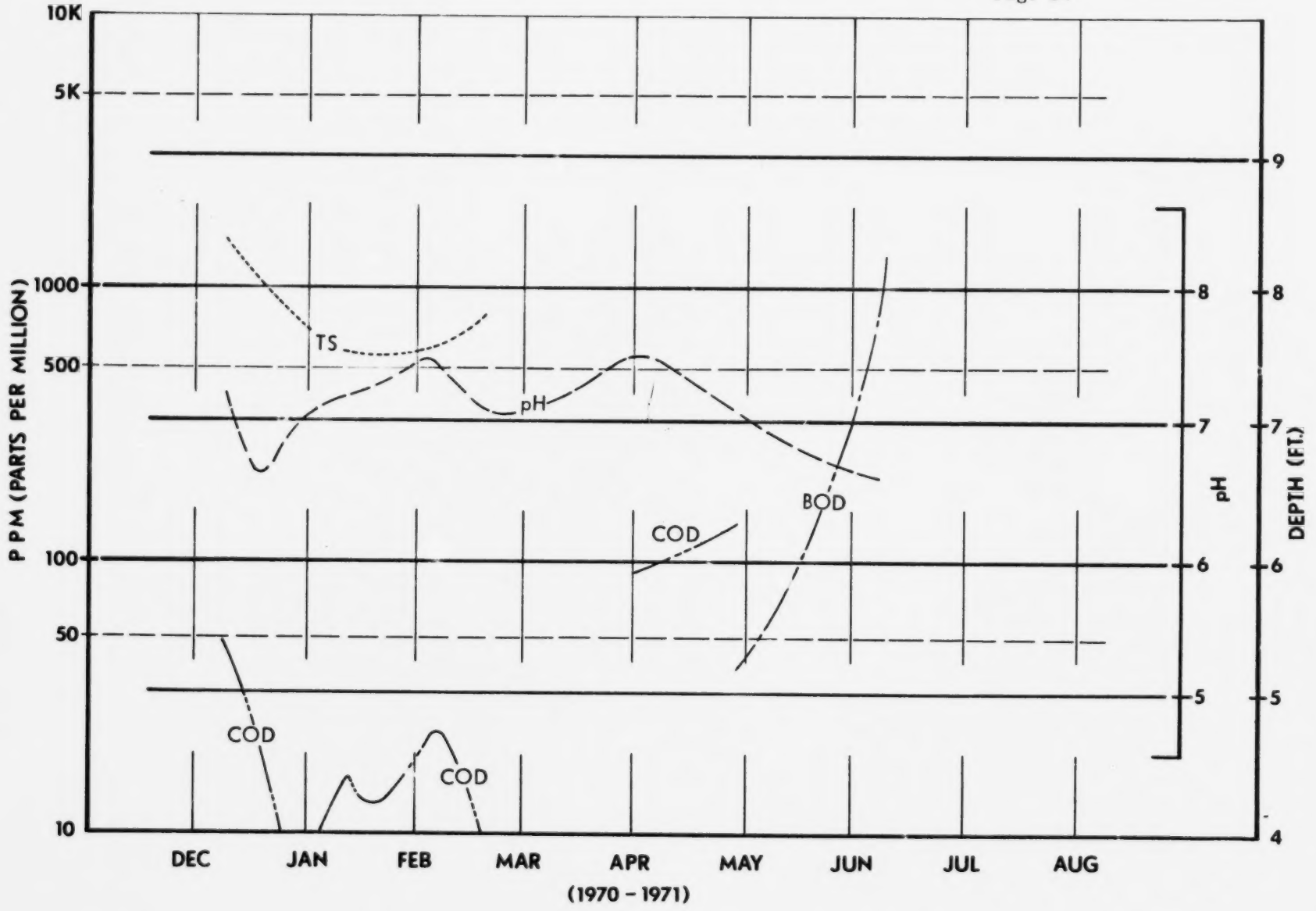
Fig. 33



TEST WELL 11-C

MATERIAL TESTED Pond-Seal

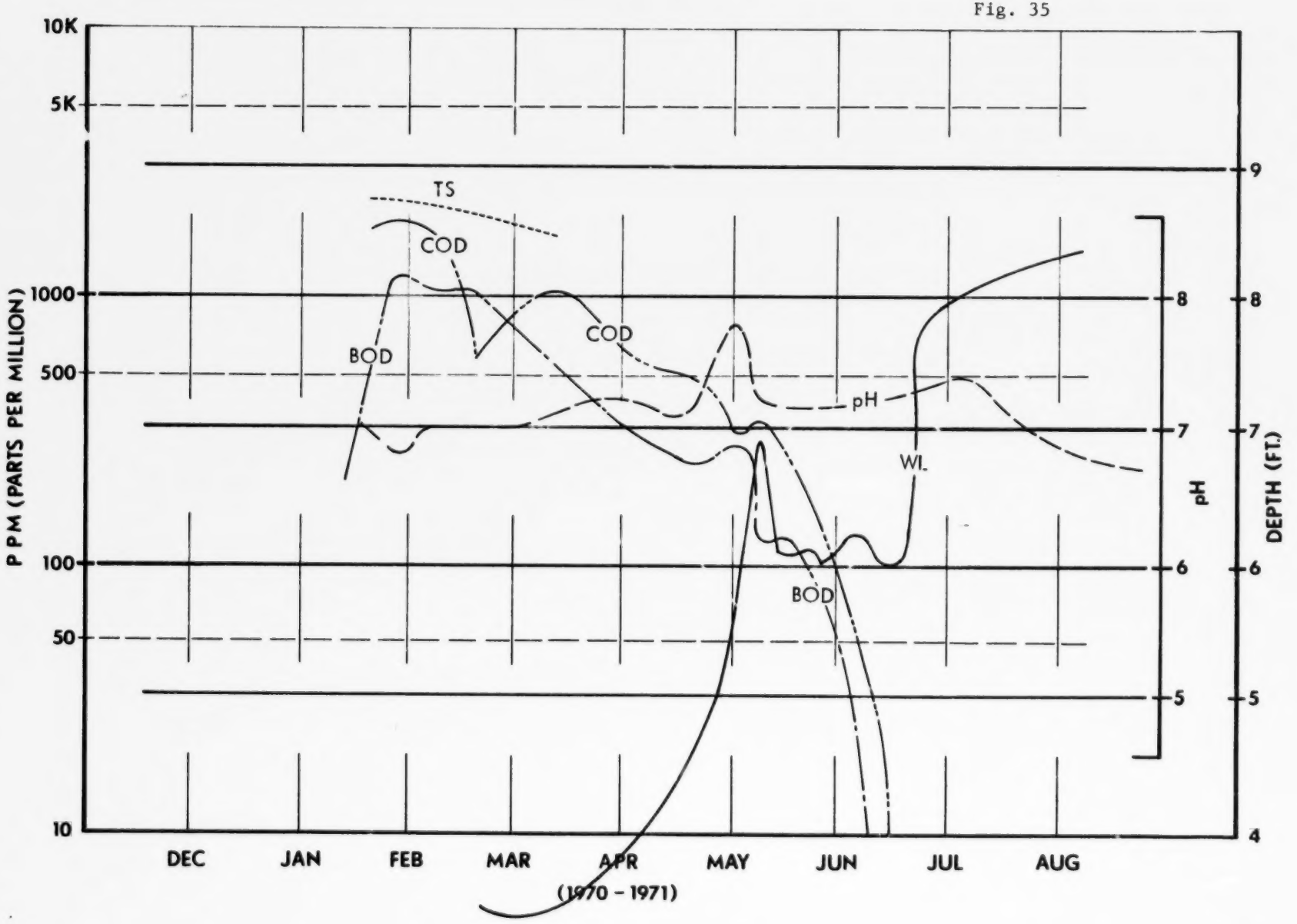
Fig. 34



TEST WELL 12-E

MATERIAL TESTED Asphalt Paper

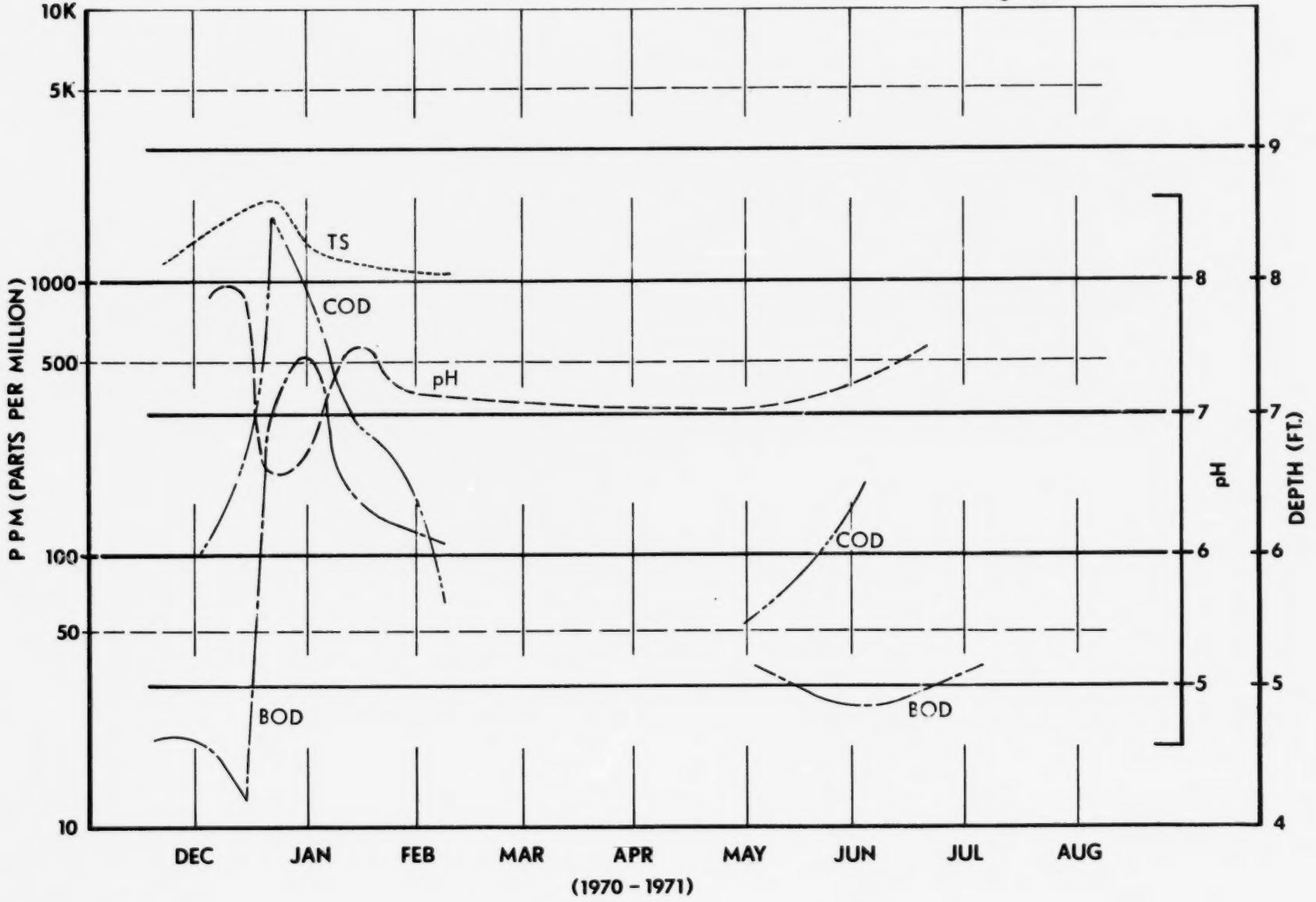
Fig. 35



TEST WELL 12-C

MATERIAL TESTED Asphalt Paper

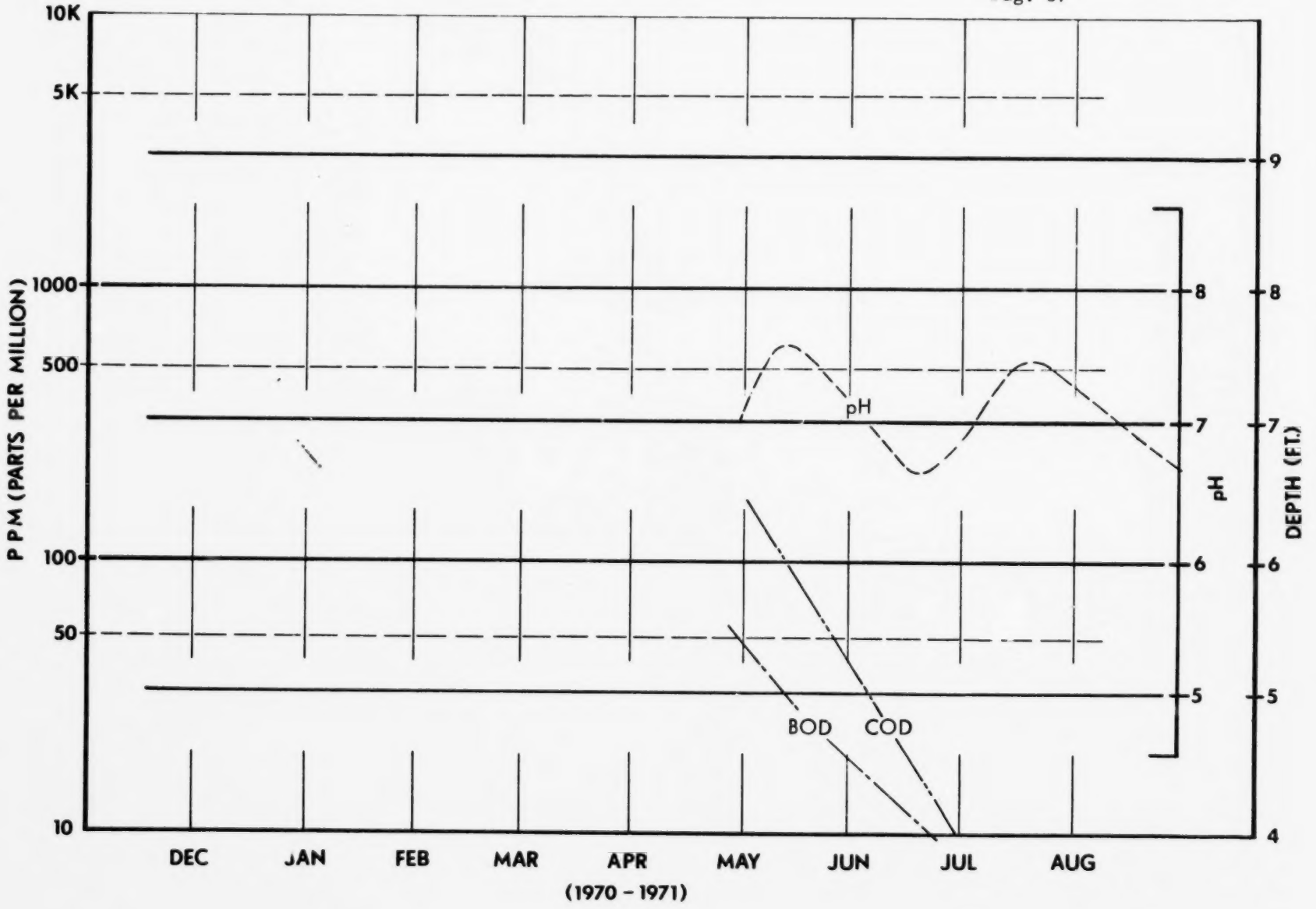
Fig. 36



TEST WELL 12-W

MATERIAL TESTED Asphalt Paper

Fig. 37



ECONOMIC ANALYSIS OF LANDFILL LINING

The choice of acceptable landfill sites in any locale must satisfy two fundamental requirements: ecological compatibility and economic justification. It is assumed that preliminary analysis of the municipal waste management problem in the locale has indicated that the sanitary landfill is the most feasible method of waste disposal. The problem, then, would be to locate usable, available land at reasonable cost and proximity to the community being served. A second problem would be to satisfy the health and environmental factors associated with waste disposal.

The final choice of the landfill site would require a compromising in cost considerations and convenience, without compromising the ecological requirements. If a landfill site cannot be conditioned (if necessary) to prevent contamination of the local surface waters and ground waters, then it must be rejected as a possible choice.

The cost of conditioning a potential landfill site is the subject of this chapter of the report. A hypothetical case will be considered, involving a distant Site A, which requires no conditioning (i.e., the surface and ground water problem is negligible) and a nearby, Site B, which would threaten the water resources, if the latter were not protected in some manner.

The cost of treating or preparing the site to prevent contamination of the surroundings must be determined and added to the land acquisition costs. The average haul distance becomes the variable which determines the long-term economics of site choice. The simple equation below illustrates the relation between the significant parameters:

$NT_a \times CTM + A_{ac} = NT_b \times CTM + B_{ac} + P_{cb}$, where

N = Number of hauling trips during the existence of the fill

T_a = Average round trip distance to Site A

T_b = Average round trip distance to Site B

CTM = Cost per trip mile

A_{ac} = Acquisition cost, Site A

B_{ac} = Acquisition cost, Site B

P_{cb} = Amount which can be spent during the existence of the Site B choice for surface and ground water protection (sealant materials or other methods), including additional labor and equipment cost

It is assumed that the final land use and land value will be equal for both sites. It is also assumed that the hauling cost per mile and available soil cover material will be equal for either choice. One could have better access routes than the other, thus altering the cost per trip mile and number of trips per day. If the acquisition cost for each site is equal, or nearly the same, the equation reduces to

$$P_{cb} = NCTM\ (T_a - T_b)$$

This is a linear function, which simply means that the shorter the average trip distance (T_B) compared to the alternate Site A, the greater the financial justification for investing in ground water protection at Site B, all other factors being essentially equal.

A community of 50,000 population generates a waste load of about 115 tons per calendar day. A total of 260 collections days (typical municipal program) per year requires an average disposal of 160 tons of waste per day. Assuming eight tons per collection, 20 average round trips would be required per day to transport the waste load to the selected disposal site. Referring to the simplified equation, if the difference in average round trip distance between Site A and Site B is 20 miles (i.e., Site B is assumed to be 10 miles nearer the

center of the municipal collection area), the "allowable" site protection cost P_{cb} can be calculated, assuming $1 per trip mile saved.

$$P_{cb} = 20\ (1.00)\ (20) = \$400 \text{ per collection and disposal day (260 days per year, assumed)}$$

This example illustrates that $400 per collection day could be spent to protect the ground water at Site B, if this were the only consideration affecting the decision economics-wise.

The area of landfill to be treated for a 160-ton daily waste load is computed to be about 800 square feet per day (assuming 35 acre-feet/50,000 population). Therefore, if $400 daily is saved by selecting the nearer Site B, then 50 cents per square foot per day would be invested in ground water pollution control methods in the example cited. This includes the labor and materials required. Cost of equipment required to perform the work should be considered and capitalized in the cost accounting procedure.

If there is a major difference in land acquisition costs or the other considerations assumed to be equal in the example cited, then these factors must be taken into account and the decision influenced accordingly. Usually the nearer landfill sites will be more expensive real estate by several orders of magnitude.

Cost of materials used in this project are not quoted, since the specifications cannot be cited and the time and place of procurement would cause prices to vary beyond the limits of useful information. Each material should be evaluated by a prospective user on the basis of local availability and cost.

REFERENCES

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5. "Landfills and Ground Water--A Review of 'Effects of Refuse Dumps on Ground Water Quality,'" California State Water Pollution Control Board, Pub. 24, 1961. *Public Works*, Vol. 94, January 1963, pp. 141-142.

6. Mannion, J. J., and D. J. Porter, *Soil Sealing Chemicals and Techniques*, Report to the Office of Saline Water, U.S. Department of Interior, Contract No. 14-01-0001-1289, June 1968.